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Pilot Study for Removal of Arsenic from Drinking Water at the Fallon, Nevada Naval Air Station

Rubel and Hager, Inc., Tucson, AZ

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16. ABSTRACT

This report presents the results of pilot plant testing of two treatment methods capable of removing arsenic from drinking water; activated alumina and ion exchange. Using the Naval Air Station (NAS) drinking water (raw water arsenic concentration = 0.080 - 0.116 mg/L) for evaluating the efficacy of treatment under several different conditions the activated alumina and ion exchange systems were operated through three loading and regeneration cycles each. The major water quality factors affecting the removal of arsenic by these methods were pH of feed water, arsenic concentration, sulfate concentration, and alkalinity. The major operational factors affecting removal were flow rate, down time, and media clogging. The report presents estimates of capital and operating costs using the activated alumina method at optimum pH (5.5) for each of three small community systems currently using water from the same aquifer.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the enviornment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Small water treatment plants have the most difficult time complying with the Safe Drinking Water Act because of limited operating funds and lack of well-trained operators. The research reported in this study of arsenic removal is applicable to the small community water treatment system. Pilot plant information which compares several treatment alternatives for removal of arsenic contamination is provided along with preliminary cost estimates for three small communities all using the same quality groundwater.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

Many small communities are faced with contamination of their groundwater by inorganic chemicals. Arsenic contamination can be the result of man-made toxic compounds leaching into the groundwater or the result of natural contamination by dissolution of minerals from subterranean strata. Regardless of the source of contamination, most small communities having arsenic concentration higher than the USEPA Maximum Contaminant Level (MCL) of 0.05 mg/L in their drinking water do not have existing treatment facilities which can be modified to remove the arsenic down to acceptable levels.

The Department of the Navy through an interagency agreement with the Drinking Water Research Division, ORD, USEPA conducted a research project to study arsenic (0.1 mg/L) removal from the drinking water (ground water) at the Fallon, NV Naval Air Station. Pilot scale tests were carried out by Rubel and Hager, Inc. (Tucson, AZ), a sub-contractor, in a mobile testing trailer for approximately 13 months. The treatment systems studied were activated alumina and ion exchange. Three columns containing 1 cu ft of media were used; two were packed with activated alumina (Columns A & B) and the other with a strong base anion exchange resin (Column C).

Column A treated water which was acidifed to pH 5.5. Column B and C treated the water with no pH control (pH 9.0). Test results showed that activated alumina treatment of water at pH 5.5 was by far the most efficient of the three test processes for removing arsenic. Column A was exhausted in 3 months, column B in two days, and column C in one day. Each column was loaded, exhausted and regenerated three times (three cycles) in the course of the study to detect any effects on the capacity. No significant changes in media capacity were observed through the three cycles. In Column B, silica and fluoride were removed along with the arsenic. Column A also removed fluoride but not silica. Column C preferred sulfate to arsenic which is typical for a strong base anion resin. The following table summarizes the results of arsenic removal through each column.

Column ID	Bed Volumes[1] Media Exhaustion	Capacity of media[2]	Flow rate (gpm/ft^3)
A (pH 5.5)	24,000	665	1.0
B (pH 9.0)	480	9.4	1.5
C (pH 9.0)	400	10.8	1.5

[1] Bed volumes of water treated until effluent As = influent As
[2] As retained on column at media exhaustion grains/cu ft.

The pilot study included tests for processing of the regenerant wastewater for disposal. In addition, preliminary design and cost estimates were prepared for full scale activated alumina treatment systems for the Naval Air Station (1.0 mgd), City of Fallon (3.45 mgd) and the Fallon Indian Reservation (0.14 mgd) as part of this study. All three water supplies use the same groundwater source containing arsenic.

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INTRODUCTION

The Western Division Naval Facilities Engineering Command (WESDIV) of San Bruno, CA through an Interagency Agreement (IAG) with the U.S. Environmental Protection Agency sponsored a pilot plant evaluation of arsenic removal from drinking water at the Fallon, NV Naval Air Station (NAS). A subcontractor, Rubel and Hager, Inc. (R/H) of Tucson, AZ, an engineering consulting firm, was responsible for conducting the pilot plant study at the NAS. Although the NAS, City of Fallon, and the Fallon Indian Reservation were the primary recipients of this information the research data was developed for use by other small communities in determining cost effective treatment alternatives for removing arsenic from drinking water.

The scope of work required a series of arsenic removal treatment tests on the groundwater supply at NAS Fallon. The studies included data acquisition and evaluation of three separate treatment modes employing two different media. The three treatment processes were as follows:

A. Granular activated alumina with pH adjustment

B. Granular activated alumina without pH adjustment

C. Strong base anion exchange resin without pH adjustment

Each treatment mode was evaluated through three complete treatment cycles (a cycle being composed of one treatment run and one regeneration) or for a maximum test duration of one year. The initial contract included two months of testing with an option for a ten month extension.

The treatment media to be used were:

1) Alcoa F-1(1) granular activated alumina (28 to 48 mesh)

2) Dow Chemical Company Dowex SBR(2) strong base anion resin.

The arsenic concentration in the Fallon NAS water supply was measured at 0.110 to 0.120 mg/L which exceeded the maximum contaminant level requirement of 0.050 mg/L established by the USEPA and the Nevada State Health Division of the Bureau of Consumer Health Protection Services. A complete raw water analysis is shown in Table 1. Since all treatment methods were evaluated using chlorinated feed water the arsenic was assumed to be in the +5 valence form. The primary objective of the test project was to develop information which would lead to the design and economical installation of cost effective treatment systems which would provide potable water in compliance with the maximum contaminant level for arsenic.

Activated alumina has been successfully demonstrated through pilot plant testing by Rubel and Hager, Inc. to economically remove excessive levels of arsenic from natural groundwater supplies. High efficiency arsenic removal was accomplished during previous[3, 4] projects by means of lowering the raw water pH to the 5.3-5.7 range. This pH adjustment achieved an optimum condition for elimination of interference from other ions present in the natural water and attraction for the arsenic ions.

USEPA has also conducted field studies which have successfully demonstrated removal of arsenic from natural groundwater supplies by means of activated alumina with and without pH adjustment. Bellack[5] reported on successful arsenic removal using activated alumina. Other laboratory studies employing activated alumina as well as other adsorbants for arsenic removal from spiked distilled water and saline solutions have also been conducted. Varying degrees of success were achieved during these studies. A report prepared by Gupta and Chem [6] describes some of the laboratory achievements in this area.

Table 1. Fallon NAS Raw Water Analysis*

Analyte	Mean	Range
Total Alkalinity (as $CaCO_3$)	246	228 - 263
Hardness (as $CaCO_3$)	5	4 - 6
Calcium	1	0 - 2
Magnesium	1	1
Sodium	240	223 - 266
Aluminum	0	0
Chloride	101	87 - 120
Sulfate	96	88 - 120
Fluoride	0.788	0.70 - 1.10
Arsenic	0.103	0.080 - 0.116
TDS	535	495 - 560
pH (units)	9.1	9.0 - 9.1
SiO_2	28	28 - 34.

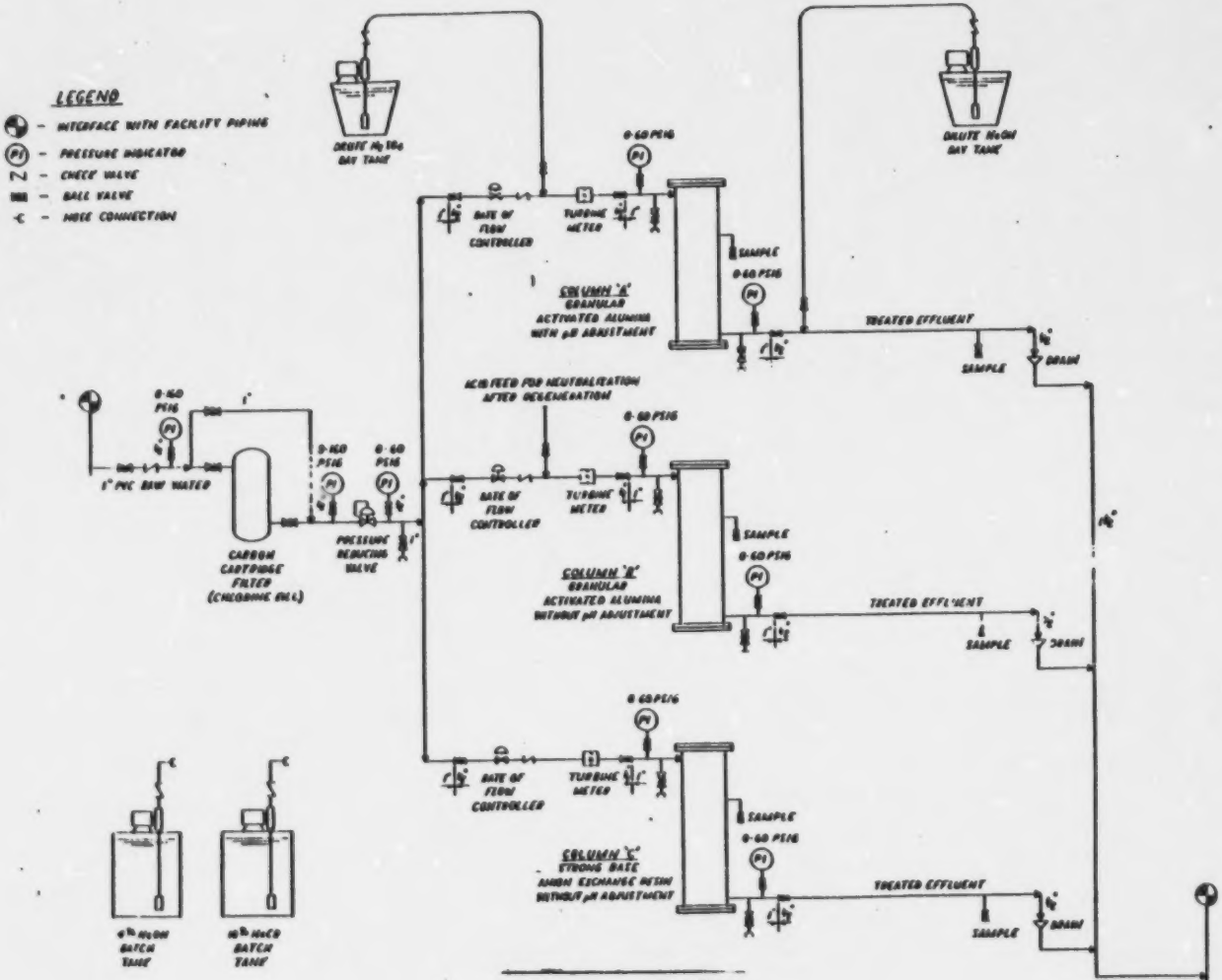
*Values in mg/L except as noted.

Strong base anion exchange resin has been successfully utilized in laboratory tests using spiked distilled water and in field studies with natural water. These test results indicated potential for an economically acceptable alternative method for removing excessive levels of arsenic from potable water supplies.

The three treatment methods were thoroughly evaluated during this pilot test project. No promise of economical arsenic removal was realized in the pilot test work in either Method B or Method C. However, the test work on activated alumina at pH 5.5 provided information that confirmed that this method can provide arsenic removal at reasonable cost. The resulting information provided sufficient data for conceptual designs for arsenic removal treatment plants at the NAS, City of Fallon, and the Fallon Indian Reservation.

TEST APPARATUS

The pilot plant apparatus consisted of three separate systems, one for each treatment mode, piped in parallel (Figure 1). Each pilot treatment system was designed to treat the well water at a maximum flow rate of 1 1/2 gpm at 50 psi maximum working pressure. The well water was pumped to the test site by NAS through a 1-inch PVC schedule 80 pipe at an approximate pressure of 75 psig (range 150 psig max., 50 psig min.). The water flowed through a five micron powdered activated carbon cartridge filter (for removal of chlorine) and a pressure control valve into a 1-inch manifold. The manifold branched into three separate systems, one for each treatment mode. There was one treatment vessel (ten inch diameter by sixty inches high column) containing 1.0 cu. ft. of treatment media in each system. The



Arsenic Removal Pilot Plant
Schematic Flow Diagram

FIGURE 1

treatment media consisted of Alcoa activated alumina (grade F-1, -28+48 mesh) in column A and B and a Dow Chemical Co. strong base anion resin (Dowex SBR, -20+50 mesh) in column C.

The treatment vessels had removable heads, top and bottom. The underdrain section occupied the bottom six inches of each column and the treatment media twenty-two inches. The remaining height was available for media expansion and freeboard.

The test apparatus was piped for manual operation with each treatment system independent of the other two. Each system had isolating valves, a check valve, a rate of flow controller, a flow totalizer, pressure indicators, sample points, hose connections for backwash/regeneration procedures and, where required, connections for chemical feed. There were also separate dilute acid and caustic feed subsystems for pH adjustment for the Column A treatment system. These subsystems consisted of day tanks and diaphragm type metering pumps, with foot valve, injection cocks, and anti-siphon devices. Lastly, there were separate regeneration caustic and salt feed subsystems. These subsystems consisted of batch tanks and diaphragm type feed pumps.

The entire treatment system was mounted in an insulated laboratory trailer. The trailer was thirty feet long by eight feet wide by eight feet high. In addition to the pilot plant equipment, the trailer housed a chemical laboratory which was equipped to perform all analyses required during the duration of the test program.

The trailer was originally located at the south entance of the Pressure House (Building No. 311) at NAS Fallon, Nevada. Electrical service

for the trailer was mounted on the outside of the building at the west side of the south entrance to the base.

The feed water supply pipe was also provided at that location. Treated water and regeneration wastewater was discharged to a waste sump at the east side of the south entrance. The regeneration wastewater was adjusted to a 5.0-6.5 pH, for wastewater experiments prior to disposal.

During the test program, the laboratory trailer was relocated to another side at the NAS Fallon South Hangar area to provide access for a new construction project at the original site.

PILOT TEST PROGRAM

The pilot test program included data acquisition and evaluation for three cycles for each of the following treatment modes:

A. Granular Activated Alumina with pH adjustment to pH 5.5

B. Granular Activated Alumina without pH adjustment (raw water pH) Upon completion of this mode, this column was used on supplementary cycles having pH adjustment.

C. Strong Base Anion Exchange Resin without pH adjustment.

One cycle included one treatment run through exhaustion of the media and one media regeneration.

The one cubic foot of treatment media was placed in the respective treatment vessels. The volume was determined by weight using manufacturer's published data for material density (Alcoa F-1 is 52 lb./ft^3 and Dowex SBR is 44 lb./ft^3). Bed volumes were also measured. The media was carefully backwashed for removal of fines; this was accomplished by running raw water upflow through each bed at a flow rate designated by the media

manufacturer for 75 percent bed expansion at the existing water temperature. The backwash was continued for twenty minutes or until all media fines had been flushed from the bed. Extreme care was exercised to prevent carryover of any media from the vessel during backwash. After backwash had been completed, the ion exchange resin in Mode C was regenerated with a 10 percent NaCl solution per the regeneration procedure explained later in this section.

The first cycle for each treatment method was started at approximately the same time. Initially, each mode treated the water at the same flow rate, 1 1/2 gpm. This flow rate was established as an optimum during previous pilot test programs. Increasing the flow rate may lower the removal efficiency; decreasing the flow rate may or may not increase efficiency, but does extend the test duration. This was monitored closely during the testing. For Column A the treatment runs were extremely long that permitted iron deposits to build up in the media. This resulted in loss of treatment efficiency. Therefore, after 40 percent of the first treatment run, the flow rate was permanently changed to 1 gpm. This change alleviated the problem and improved the treatment efficiency.

Column B and C treatment runs were very short and thus, no flow rate adjustments were considered for those modes. The cycles for the different treatment modes were not completed simultaneously. There was no attempt to synchronize start and/or completion of cycles of the different treatment modes. Pilot test operation for all practical purposes was continuous. Start of one cycle followed completion of the previous cycle for each treatment mode.

Raw and treated water samples for each treatment mode were collected at least once per day. During each regeneration, backwash and regeneration wastewater grab samples were collected at five and ten minute intervals. Grab samples were also collected for each unit of pH interval drop during regenerations in which there was a neutralization step. Composite samples were taken during each step of the regeneration phase.

Duplicate samples of raw and treated water were accumulated in eight ounce polyethylene sample bottles once per week during the duration of each test run; duplicate samples were also collected of composite regeneration wastewater. Samples were also provided to the EPA for verification analyses at their laboratory. Upon completion of each treatment run prior to backwash and regeneration. Five hundred gram treatment media samples were removed from each bed. These samples were delivered to the USEPA (Region IX) for determination of reactivity, corrosivity, ignitability, composition of the waste, and the mobility of toxic species present in the waste.

Laboratory analyses of all water samples were conducted at the test site in the field laboratory. All glassware and reagents were purchased new specifically for this project. All reagents, glassware and equipment were in full compliance with requirements of "Standard Methods for the Examination of Water and Wastewater - 15th Edition, 1980" [8]. Reference samples of water containing arsenic, fluoride and aluminum were provided by the EPA for analytical quality assurance tests. The results of the test samples met EPA standard requirements. A list of analyses for raw, treated and regeneration water is listed in Table 2. Test methods for each analyte are listed in Appendix C.

Table 2. Analytical Tests for Water Samples

	Daily	Weekly
Treatment Methods A & B (activated alumina)		
Raw and Treated Water	pH arsenic fluoride aluminum silica alkalinity TDS	total hardness carbonate bicarbonate sodium sulfate color
Regeneration Wastes (samples taken at each regeneration)		
	arsenic aluminum pH fluoride chloride sodium	calcium magnesium sulfate TDS alkalinity total hardness
Treatment Method C (anion exchange)		
	pH arsenic alkalinity TDS sulfate chloride fluoride	

Upon start of testing each treatment method was operated independently. A description of operation of each method follows:

A. Activated Alumina with pH Adjustment

The raw water was treated in a downflow packed bed configuration. The flow rate was controlled initially at 1 1/2 gpm and then reduced to 1 gpm at 40 percent through the first run. Prior to entering the treatment vessel

the raw water was adjusted to pH 5.5 using a dilute solution of sulfuric acid (H_2SO_4). After treatment a solution of dilute NaOH was fed into the effluent water to raise the pH to 7.5. Raw and treated water samples were taken at least once per day and analyzed for pH, arsenic, fluoride, aluminum, silica, alkalinity, and total dissolved solids. Raw and treated water samples were taken at least twice per week and analyzed for total hardness, carbonate, bicarbonate, sodium, sulfate, and color. Regeneration wastewater samples were analyzed for arsenic, aluminum, pH, fluoride, chloride, sodium, calcium, magnesium, sulfate, total dissolved solids, alkalinity and hardness.

Each treatment run extended until the arsenic level in the treated water was at (or very near) the arsenic level in the raw water. Upon completion of each run, a sample of expended media was removed. The treatment bed was then backwashed with raw water at a flow rate to expand the bed 50-75 percent. Backwashing lasted ten minutes or until the backwash water was visually void of fines. Upon completion of backwash, the treatment media was drained. After draining, a 24-gallon batch of 4-4.5% NaOH solution was pumped upflow through the bed for a 35 minute period. Following upflow regeneration, the bed was rinsed with new water at 1 1/2 gpm for 60 minutes and then drained again. The bed was then regenerated downflow with a 24-gallon batch of 4-4 1/2% NaOH during a 35 minute period. Upon completion of the downflow regeneration, the bed was flushed with raw water at a flow rate of 1 1/2 gpm for a period of fifteen minutes.

At this point, the raw water pH was adjusted to 2.5 starting the neutralization phase of the regeneration. The effluent pH at the start of

neutralization was over 12 and slowly dropped over an extended period. When the effluent pH dropped to 9.0 the influent adjusted pH was raised from 2.5 to 4.0 at which point the next treatment run began. There was still no requirement to raise the effluent pH as it was still high. When the effluent pH dropped to 6.5, the influent adjusted pH was raised from 4.0 to 5.5 where it remained throughout the treatment run. The effluent pH was adjusted by addition of dilute caustic to the 7.5 level.

All backwash and regeneration wastewater was adjusted to pH 5.0-6.5. This pH change produced an alum type sludge which coprecipitated most of the arsenic from the wastewater. The arsenic level in the wastewater supernatant was very low (0.1 mg/L) and therefore was discharged into the wastewater system. Accounting of chemical consumption was maintained during each cycle.

B. Activated Alumina without pH Adjustment

This method was identical to method A above except that there was no pH adjustment during the treatment run. The only pH change that took place was during the neutralization step after regeneration.

Backwash and regeneration procedures were also the same as in method A above except that the acid feed adjusting the pH to 2.5 was terminated when the effluent pH dropped to 9.0. The next treatment run began then. There was no further pH adjustment until the neutralization phase of the next regeneration.

C. Strong Base Anion Exchange Resin without pH Adjustment

The raw water was treated in a downflow packed bed configuration at 1 1/2 gpm. Raw and treated water samples were taken at least once per

day and analyzed for pH, arsenic, alkalinity, total dissolved solids, sulfate, chloride, and fluoride. Regeneration wastewater samples were analyzed for arsenic, pH, fluoride, chloride, sodium, calcium, magnesium, sulfate, total dissolved solids, alkalinity and total hardness. The treatment run extended until the arsenic level was at or very near the arsenic level in the raw water.

Upon completion of each test run, a sample of expended media was removed. The treatment bed was then backwashed with raw water at a flow rate to provide a bed expansion of 50 percent. The backwash was a minimum of ten minutes or until the backwash water was void of fines. Following backwashing, the treatment vessel was drained to the top of the treatment media and regenerationed downflow at 1 gpm flow rate using 125 gallons of 10 percent sodium chloride. After downflow regeneration, a 1 1/2 gpm raw water downflow rinse took place for 25 minutes. Upon completion of the rinse, the next treatment run began.

Results and Discussion of Pilot Tests

The format for reporting the results of the pilot study is separated into unique discussions of each column operation. As pointed out in the pilot test program, three columns were operated simultaneously using the same chlorinated, carbon filtered water as feed to the columns. Raw water analysis appears in Table 1. Throughout the study the concentration of various raw water components changed slightly. The most significant change was arsenic. At start up (day 1) arsenic was 0.089 mg/L. Near the end of the study arsenic was 0.110 mg/L. The sulfate concentration of the raw water (97 mg/L) was increased to approximately 360 mg/L by

addition of sulfuric acid used to lower the raw water pH to 5.5.

Method A, activated alumina with pH adjustment to 5.5, was the only pilot test method that proved successful. Both method B and method C pilot test operations were completed in a very short period while method A pilot test operations extended for almost one year. Because the pilot test equipment used for method B and C became available for investigative work after the completion of these studies, additional tests in Column B using activated alumina with pH adjustment were conducted. Using a fresh bed of activated alumina with pH adjusted to 6.0 (in lieu of 5.5) a test was run for comparison with method A Run No. 1 (A1). After completion of that test and a subsequent regeneration, a second test was run with pH adjusted to 5.5, but with flow directed up through the bed (in leiu of down) for comparison with the method A downflow test run. The results of these two test runs are discussed in this section along with summary of pilot test operation for method B (activated alumina without pH adjustment) and method C (strong base anion exchange resin).

Results of Method A Operation

The three test cycles of Method A experiments were labeled A1, A2, A3 respectively. The first test run, A1, commenced on December 2, 1981. The flow rate was initially controlled at 1.5 gpm. That, however, was reduced to 1.0 gpm on January 5, 1982 after treating 9,600 bed volumes (72,000 gallons). As explained previously, this flow rate reduction for method A, was necessary to alleviate performance problems resulting from buildup of precipitated iron deposits in the treatment media. This suspended material was iron corrosion products emitting from the wells

and several miles of transmission piping. Later investigations revealed that periodic work on the NAS Fallon wells and piping system were dislodging large amounts of these iron deposits which were periodically dispersed into the transmission piping. The material passed through the pilot plant cartridge prefilter prior and was removed by the granular activated alumina. The filtered material was skimmed off of the top of the treatment bed, and later successfully backwashed from the bed twice without disrupting the process.

The raw water arsenic level varied from 0.085 to 0.100 mg/L throughout this first run. However, during the last four days of the run the level climbed to 0.110 mg/L. The cause of the variation in raw water arsenic level was not determined although the changing of well pump operations is a probable explanation. The run was terminated on April 4, 1982 (111 days) after treating 24,480 bed volumes (183,600 gallons).

Figure 2 shows that arsenic was nondetectable in the effluent (treated water) up to a treatment volume of about 8,500 BV (63,000 gallons). The effluent arsenic concentration reached the MCL (0.05 mg/L) at 15,536 BV (116,210 gallons). The media continued to remove arsenic up to 24,500 BV (183,600) where effluent arsenic concentration reached 0.085. At this point the adsorption cycle was terminated because the activated alumina capacity was nearly exhausted.

The arsenic removal capacity calculated for test run A1 is shown in Table 3. The alumina removed 325 grains (20.6 grams) of arsenic before any breakthrough occurred. The test run was continued until the effluent arsenic concentration reached the influent concentration. Total capacity

Table 3. Summary of Column Capacity

grains/cuft (g/M^3)

Test Run ID	Capacity at first arsenic detection	Capacity at arsenic MCL	Capacity at Media Exhaustion
A1 (Virgin)	325 (747)	540 (1242)	655 (1507)
A2	42 (95)	490 (1107)	611 (1405)
A3	246 (566)	646 (1486)	730 (1679)
B1 (Virgin)	N.C.*	18.3 (42.1)	19.3 (44)
B2	2.6 (5.8)	5.0 (11.3)	5.2 (11.0)
B3	2.6 (5.8)	3.2 (7.2)	3.7 (8.5)
C1 (Virgin)	N.C.*	N.C.*	8.2 (18.5)
C2	5.7 (13.0)	10.1 (22.8)	10.2 (23.)
C3	9.9 (22.4)	13.8 (31.2)	13.9 (31.4)
B4 (Virgin)	241. (554)	433. (979)	536. (1233)
B5	D+	294. (676)	488. (1122)

* Samples not collected at low bed volume
+ D - All samples contained detectable arsenic

calculated at this point was 655 grains cu. ft. (42.5 gram/M^3). Table 4 displays these values in terms of volume and run time.

Figure 2 displays several places where the effluent arsenic concentration decreased. During the period of March 16 through March 29 (23,278 BV), the flow was shut off to study the effect of intermittent operation. At the time of shut off, the effluent arsenic level was 0.083 mg/L; upon start-up some thirteen days later, the effluent arsenic concentration dropped to

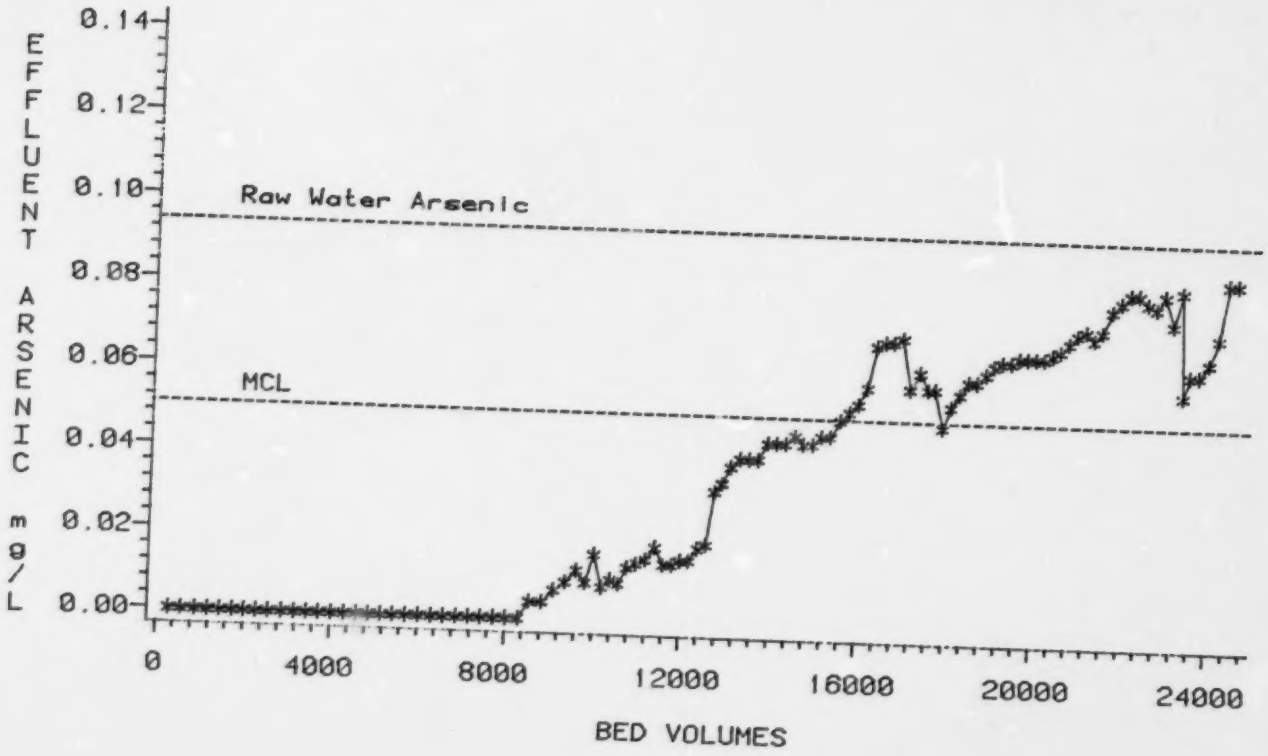


Figure 2. Column A Run 1 (pH 5.5)

Table 4. Summary of Treatment Volumes and Run Time

Test Run ID	Volume Treated - Gallons(Bed Volumes) First Arsenic Detection	Arsenic MCL	Media Exhaustion	Run Time (days)
A1	63,855 (8542)	116,210 (15,536)	183,600 (24,545)	111
A2	8,270 (1105)	96,400 (12,888)	152,900 (20,447)	105
A3	39,890 (5332)	111,700 (14,933)	158,870 (21,239)	110
B1	---	5,940 (794)	7,990 (794)	4
B2	756 (101)	1,260 (168)	1,764 (235)	1
B3	756 (101)	---	1,008 (134)	1
C1	1,590 (212)	---	3,695 (493)	1
C2	1,350 (180)	2,160 (288)	2,430 (324)	1
C3	2,160 (288)	---	2,970 (397)	1
B4	35,550 (4752)	100,165 (13,391)	130,080 (17,390)	94
B5	---	57,560 (7,695)	102,020 (13,639)	67

0.058 mg/L. During the following days after restart the treated water concentration increased reaching the 0.085 mg/L level after 6 days. This phenomenon occurs in fixed bed processes as the sorbed ions migrate deeper into the pore structures of the media, thereby exposing more external surface area to the ions in solution. Normally this new capacity is short lived and the external pore surface is soon saturated again.

The amount of acid and caustic used during A1 was as follows:

1) 66°B' Sulfuric Acid (to adjust raw water pH to 5.5) - 0.129 gal/1000 gallons treated water.

2) 50% Sodium Hydroxide (to adjust treated water pH to 7.5) - 0.075 gal/1000 gallons treated water.

However, since the addition of sodium hydroxide was undesirable for both water quality (addition of sodium) and financial reasons, it

was determined that aeration of treated water was preferable to chemical addition for neutralization. Therefore, sodium hydroxide neutralization of treated water was eliminated from test runs A1 and A3.

Blending of raw and treated water can also be utilized for neutralization. This procedure also provides an excellent opportunity for reducing operating costs and meeting the arsenic MCL without significantly varying the quality of the treated water. During the treatment run (A1) there was potential for blending 50% treated water with 50% raw water and still comply with the arsenic MCL. Since the raw water arsenic level in later treatment runs, A2 and A3 consistently exceeded 0.110 mg/L, a conservative design would provide for blending 75% treated water with 25% raw water. An analysis of the 75/25 blend is tabulated in Table 5 but shown only for Run A3 at 3,979 BV (29,760 gallons).

Regeneration for run A1 took place on April 4, 1982. Wastewater volumes included 321 liters (85 gallons) of backwash water and 1798 liters (475 gallons) of regeneration wastewater including rinse. The regeneration was carried out with two 90 liter (24 gallon) batches of 4% sodium hydroxide solution (one upflow and one downflow). Analyses of the regeneration wastewater indicated a removal of 33.6 grams (518 grains) of arsenic from the bed. A mass balance of arsenic removed during treatment and regeneration indicated that 8.8 grams (137 grains) remained on the media after regeneration (Table 6). Because of incomplete regeneration, the caustic concentration was increased from 4 to 4.5 percent for the next regeneration. Care was exercised to minimize dissolving of the alumina. The higher the caustic concentration the more aluminum that goes into

Table 5. Water Analysis*
Arsenic Removal Pilot Plant Project

Column A (activated alumina with Raw Water pH adjusted to 5.5)

Run - No. 3, Gallons Treated - 29,760
August 9, 1982

	Raw Water	Treated Water	Aerated Treated Water	Blend 75% Aerated Treated 25% Raw
P Alkalinity(as $CaCO_3$)	50	0	0	7
M Alkalinity(as $CaCO_3$)	246	30	30	74
Hardness (as $CaCO_3$)	5	5	5	5
Calcium	0	0	0	0
Magnesium	1	1	1	1
Sodium	240	240	240	240
Aluminum	0	.02	.02	.02
Chloride	101	101	101	101
Sulfate	96	290	290	230
Fluoride	0.80	0.55	0.55	0.65
Arsenic	0.110	ND†	ND	0.028
Silica	28	28	28	28
TDS	535	630	630	600
pH	9.1	5.5	7.5	8.6

*Reported as mg/L unless noted otherwise.
†ND is Non Detectable

solution; therefore, caution must be exercised when caustic concentration is increased. During neutralization of the media bed, 4.9 liters (1.3 gallons) of 66°B' sulfuric acid were used.

After completion of regeneration of test run A1 run A2 commenced on April 5 and continued until July 19, 1982 (105 days). During this run, 20,400 BV (152,960 gallons) were treated in contrast to 24,480 BV (183,600 gallons) in Run A1 at exhaustion. However, the raw water arsenic level was higher than that during Run A1; the range was 0.102 to 0.116 mg/L. In run A2 effluent arsenic concentration was below detectable

limits only during treatment of the first 1000 BV. However, the profile of Figure 3 shows that the rise of arsenic in the effluent was nearly the same as in Figure 2 beyond 12,000 BV. When the effluent arsenic was at the MCL (0.05 mg/L), the arsenic removed by the activated alumina in A2 was 490 grains/cu.ft. compared to 540 grains/cu.ft. for A1. The final exhaustive capacity (611 grains/cu.ft.) was somewhat less than that for A1 (655). Figure 3 shows the plot of effluent arsenic vs BV treated. Again, as in Figure 2 and the discussion section, there are portions of the curve showing As concentration decreasing as the system was shut down for a short period of time.

During this run several disruptions occurred. On April 15, 1982 the laboratory trailer was shut down (five hours) for relocation to the South Hangar area to avoid interference with the start of a new construction project at the original test site. On May 15, 1982, the column was backwashed to remove the solids that had accumulated at the top of the bed. On May 18 a break in an NAS facility water main resulted in a drop in system pressure and reduction in raw water flow through the pilot plant. This caused a drop in raw and treated water pH which was immediately corrected. During this treatment run (A2) 66°B' sulfuric acid consumption for adjustment of raw water pH to 5.5 was 0.131 gallons/1000 gallons treated water.

Regeneration of A2 test run took place on July 20, 1982. Wastewater volumes included 378 liters (100 gallons) of backwash water and 1135 liters (300 gallons) of regeneration wastewater and rinse. The regeneration was carried out with two 90 liter (24 gallon) batches of 4.5% sodium hydroxide

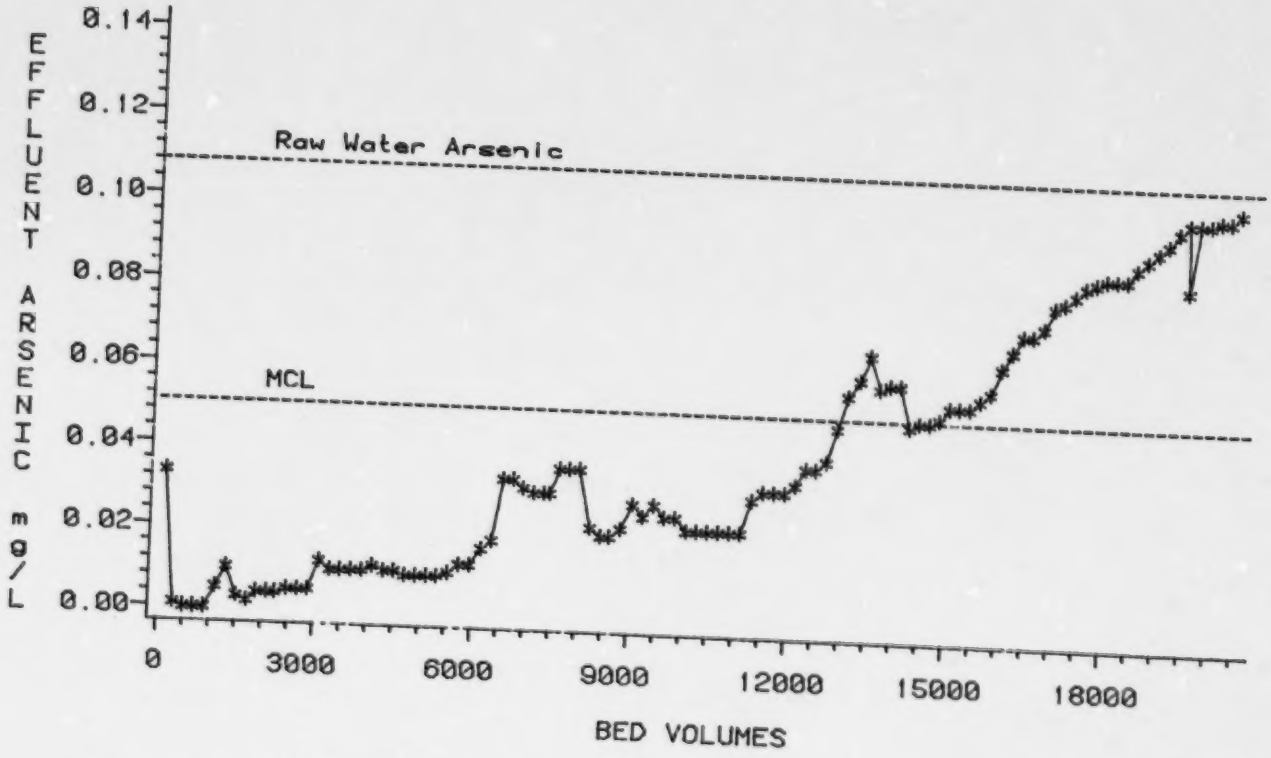


Figure 3. Column A Run 2 (pH 5.5)

solution. Analyses of the regeneration wastewater indicated a removal of 34 grams (527 grains) of arsenic from the bed. Again, there is an apparent retention of 5.4 grams (84 grains) of arsenic in the bed in addition to the 130 grains of arsenic remaining after regeneration A1 (Table 6). During neutralization 5.3 liters (1.4 gallons) of 66°B' sulfuric acid were used.

Run A3 started on July 20, 1982 and was terminated on November 8, 1982 (110 days). During this run 21,239 BV (158,870 gallons) were treated in contrast to 20,459 BV (152,960 gallons) during Run A2 and 24,545 BV (183,600 gallons) during Run A1. The raw water arsenic level ranged from 0.109 to 0.113 mg/L. Run A3 more closely resembles Run A1 than it does Run A2. The Figure 4 profile shows that no arsenic was detected in the effluent up to 5000 BV treated. The MCL was reached at 15,000 BV and total exhaustion (effluent As = influent As) at about 21,000 BV. Tables 3 and 4 show the tabulations of arsenic removed by the activated alumina at various points in the test run. Although the media in run A3 did not absorb as much arsenic before leakage (detection of any arsenic in the effluent) compared to run A1, the removal of arsenic up to the point where the effluent arsenic reached the MCL was higher (646 grains/cuft) than the A1 capacity (540 grains/cu.ft.). Total grains of arsenic removed was 730 versus 611 in Run A2 and 655 in Run A1. A much larger fraction of treated water was produced with an arsenic level less than 0.010 mg/L. The only disruptions that occurred during this run were two successful backwashes of the treatment bed on September 5 and October 10, 1982. During this treatment run 66°B' sulfuric acid consumption for adjustment

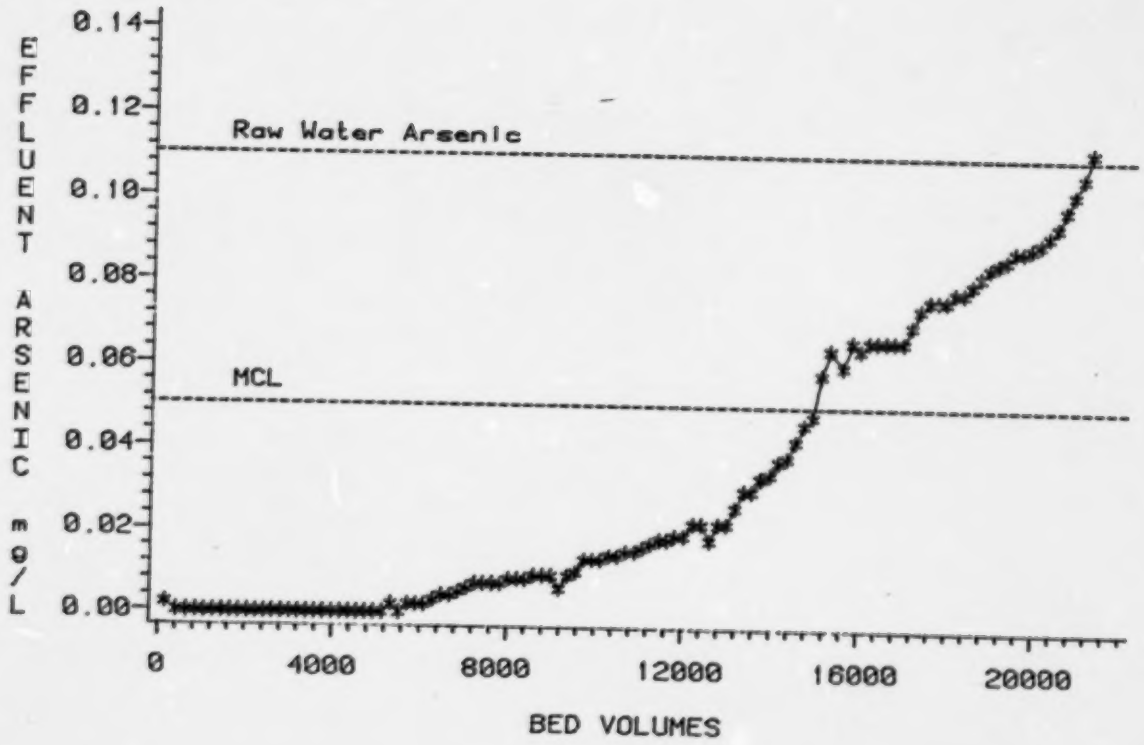


Figure 4. Column A Run 3 (pH 5.5)

of raw water pH to 5.5 remained at 0.131 gallons/1000 gallons treated water.

Regeneration of A3 test run took place on November 8, 1982. Wastewater volumes included 100 gallons backwash water and 330 gallons of regeneration wastewater including rinse. The regeneration was carried out with two 24 gallon batches of 4.5% sodium hydroxide solution. Analyses of the regeneration wastewater indicated a removal of 557 grains of arsenic from the bed. Again, there is an apparent 173 grains of additional arsenic retained in the bed (Table 6). This regeneration was terminated upon completion of the neutralization step. 66°B' sulfuric acid consumption during the neutralization step of this regeneration was again 1.4 gallons. The final 330 gallon batch of wastewater from regeneration A3 was retained for precipitation, sedimentation and sludge dewatering treatment. The results of this work will be described later in this section.

Results of Treatment Method B

Column B was packed with one cuft of F-1 Alcoa activated alumina as in column A. However, the raw water pH was not adjusted prior to treatment in the first three runs (B1, B2, B3) but treated at the raw water pH 9.0.

Column B was only operated for short periods because of low removal efficiency during the first two months of pilot plant operation. Test run B1 commenced at the same time as Run A1 and Run C1; it started on December 2, 1981 and was terminated on December 12, 1981. Column B operated at 1.5 gpm and at pH 9.0-9.1 which is the ideal pH for silica removal, but unfavorable for arsenic removal. As expected the arsenic

removal performance was very poor; arsenic removal occurred after 3 days. The raw water arsenic level was 0.090 mg/L during the test period. The treated water arsenic was measured as low as 0.008 mg/L. Due to only one sample being taken per day, there are very few data points. However, extrapolation of available data indicates that during the run, 800 BV (5940 gallons) were treated in which 24 grains of arsenic were removed. The treatment run was continued until silica removal terminated.

For a short period after arsenic removal ceased, a small amount of arsenic was desorbed from the bed. This gave an indication that at the higher treatment pH the alumina preferred silica to arsenic. Some measurable fluoride removal was also detected during the first day of the run. Figure 5 shows the plot of effluent arsenic vs bed volumes treated for all three runs of column B. Run B1 was operated with virgin activated alumina. The result is obvious compared to B2 and B3. Figure 5 shows that at pH 9 the virgin alumina removed arsenic well up to about 500 BV. Between 500 and 1000 BV the arsenic began to break through at a rapid rate. Runs B2 and B3 began breakthrough at 100 BV and increased rapidly to exhaustion at 200 BV. Analysis of the influent and effluent samples taken during the three runs revealed that silica was removed by the alumina as much as 91% at the beginning of each run. At the point where the media was exhausted for arsenic removal, silica was still being removed at nearly 60%. Table 3 shows the calculated capacity values for B1, B2, and B3 runs.

Regeneration B1 took place on December 28, 1981. Wastewater volumes included 50 gallons of backwash water and 300 gallons of regeneration

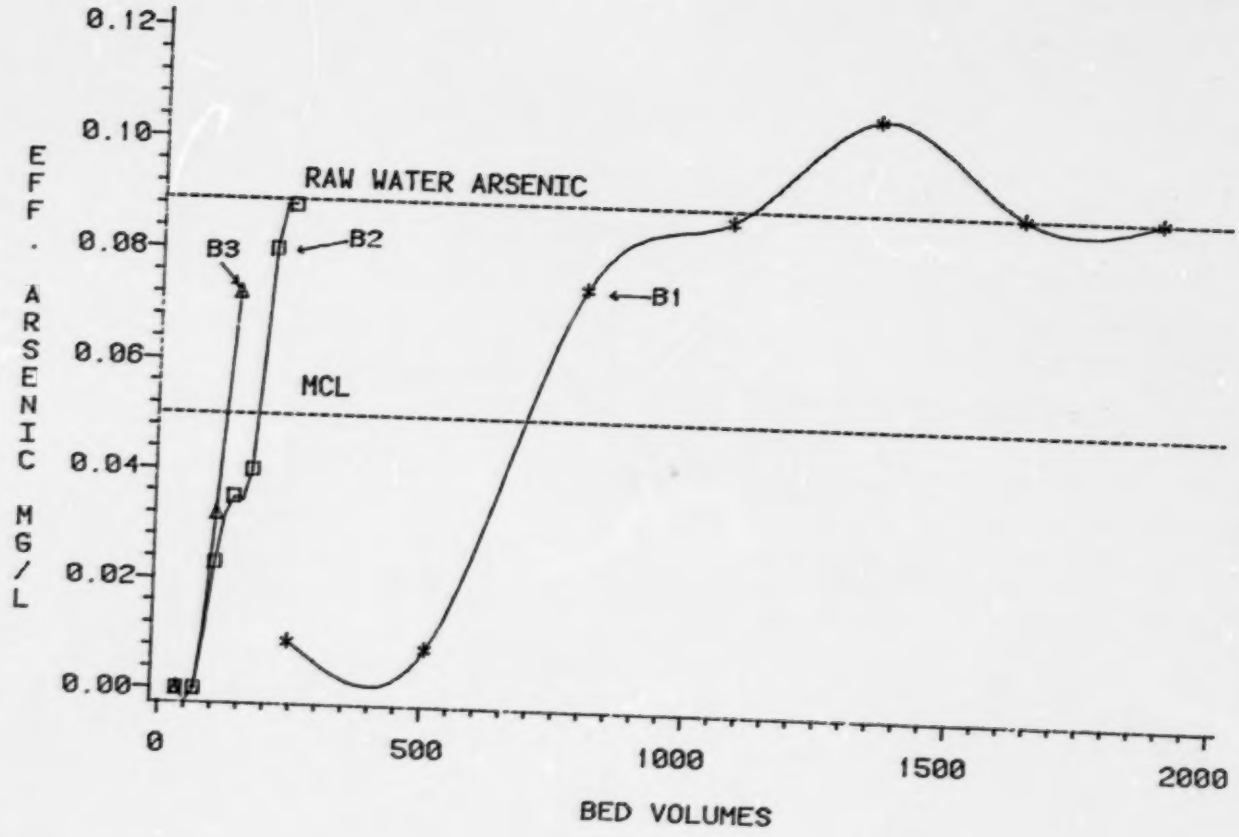


Figure 5. Column B Runs (pH–9.0)

wastewater including rinse. The regeneration was carried out with two 90 liter (24 gallon) batches of 4% sodium hydroxide solution (one upflow and one downflow). This process was also used in regeneration B2 and B3. Analyses of the regeneration wastewater indicated a recovery of approximately 8 grains of arsenic from the bed leaving an apparent 11 grains in the bed. The results of the Run B1 and Regeneraton B1 indicated that there was no promise for economical operation using NAS water for a central arsenic removal treatment plant without pH control. After completion of the downflow regeneration and rinse the treatment bed was neutralized to pH 9.0 using 66°B' sulfuric acid. Run B2 commenced immediately and was completed within one day. Samples of treated water were taken and analyzed every three hours instead of once per day. The treated water arsenic level dropped below detectable limits (.003 mg/L) during the first six hours; it then increased steadily until it reached the level of the raw water (.088 mg/L) after twenty-one hours. 202 BV (1500 gallons) of water were treated in which approximately 5.3 grains of arsenic were removed. Regeneration B2 took place on Juanuary 7, 1982 with Run B3 following immediately thereafter. The performance of Run B3 was even less attactive than that of Run B2. Finally Regeneration B3 took place on Janury 9, 1982. Upon completion of that regeneration the treatment media was removed from Column B. A fresh bed of activated alumina was placed in the column for the testing described previously using activated alumina with raw water pH adjustment.

Results of Treatment Method C

The results of method C were similar to those of method B. Column C was packed with one cubic foot of Dowex SBR anion resin (strong base anion). During the initial work with method C it became immediately obvious that sulfate was preferred to arsenic. Since the raw water contained almost 100 mg/L sulfate and less than 0.1 mg/L arsenic (ratio 1000:1), it was apparent that resin would have nearly zero capacity for arsenic. In addition, immediately after the arsenic removal is complete, it is then displaced from the resin by the sulfate. Alkalinity was also removed during the early part of the run (dropping pH); but later it is also eluted from the bed by the sulfate. Prior to regeneration after Run C1 considerable effort was expended to determine whether any work had been done to reverse the resin preference to arsenic over sulfate. Discussions with EPA officials and the resin manufacturer revealed that there was no knowledge of work having been done on this subject. Therefore, no extra effort to invent a method of accomplishing this reversal of preference was undertaken and the remaining test runs were completed.

Run C1 commenced on December 2, 1981 and was terminated on December 9, 1981. Arsenic removal took place only during the first day. The arsenic was eluted from the resin during the next two days (Figure 6.) This run was continued for four additional days to observe the sulfate removal performance. C1 Regeneration took place on December 29, 1981. Wastewater volumes included 113 liters (30 gallons) of backwash water and 625 liters (165 gallons) of regeneration wastewater and rinse water. The regeneration was carried out with 473 liters (125 gallons) of 10%

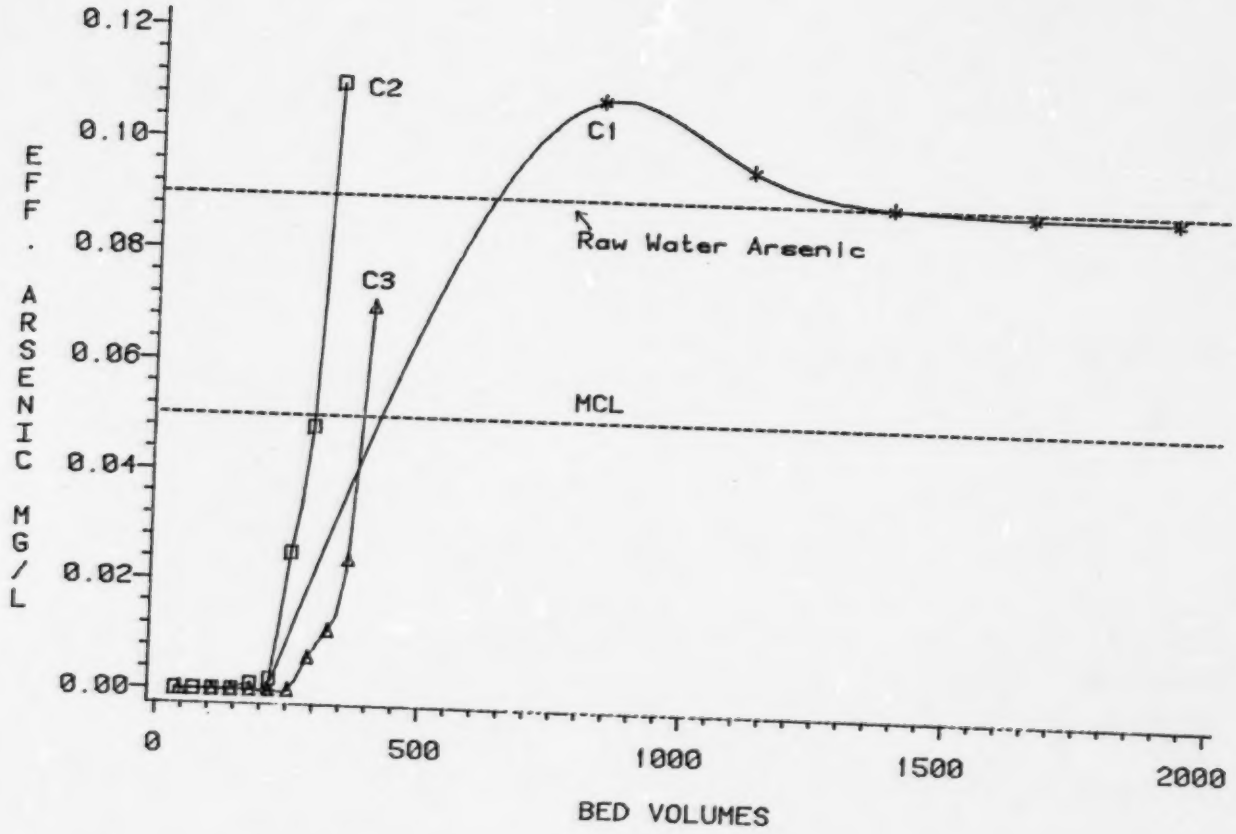


Figure 6. Column C Runs (Anion Exchange)

NaCl solution which flowed down through the bed. Following a 151 liter (40 gallon) rinse, the column was placed immediately into operation for Run C2. That process was repeated for regeneration C2 and C3. Run C2 was completed on December 30, 1981 after one day of operation (upon completion of arsenic removal). At that time sulfate removal was still 100 percent. Treated water totaled 324 BV (2700 gallons) from which 10 grains of arsenic were removed. Regeneration C2 took place on January 8, 1982 and was immediately followed by run C3. The arsenic removal of C3 was slightly higher than for C2. Regeneration C3 took place immediately after the completion of run C3 on January 9, 1982. Figure 6 shows the plot of the column C runs C1, C2, and C3. The raw water pH was not altered for the treatment in column C. As in column B, the virgin run with column C (cycle C1) broke through so rapidly that a detailed profile could not be plotted. Sample frequency was increased for C2 and C3 to describe more accurately the breakthrough point. Arsenic was not detected until 180 BV in run C2 and until 288 BV in run C3. When arsenic was detected in the effluent, exhaustion occurred rapidly. In run C2, the MCL was reached at 280 BV and exhaustion occurred at 324 BV. In run C3, the MCL was reached at approximately 380 BV and exhaustion at 400 BV. Table 3 shows the calculated capacity values for C1, C2, and C3 cycles. No further work was attempted with anion resin during the remainder of the project. There was no evidence of any opportunity for use of this treatment method in a central treatment plant for removing arsenic from the NAS water.

Results of Testing at Near-Optimum Conditions

Because of the short test runs of B1 - B3, column runs B4 and B5

were initiated to compare performance of activated alumina run at pH 6.0 to the test runs at pH 5.5 of test runs A1-A3. Therefore, on January 22, 1982 Column B was loaded with a fresh bed of virgin activated alumina identical to that which was used in column A. If successful, the benefits of operating at pH 6.0 instead of pH 5.5 would be:

1) Use of less acid for pH adjustment.

2) Higher pH of blended water.

3) Lower treated water sulfate level.

Initially, a flow rate of 1.4 gpm in a downflow configuration (similar to method A) was used. After approximately 40% of the run, the flow rate was reduced to 1.0 gpm. Run B4 was terminated on May 9, 1982 after treating 17,400 BV (130,000 gallons) for a 29 percent decrease in capacity from test run A1 at pH 5.5 (24,500 BV). Figure 7 shows the entire run of B4. No arsenic was detected in the effluent until 7000 BV were treated. A rather steady increase was then detected up to about 12,000 BV. At 12,000, 15,000, 17,000 and 19,000 (BV), the alumina bed seemed to recover some capacity. This occurred when the column was shut off for a short period of time. Table 3 shows the capacity of the alumina at various points in the run. Before arsenic detection in the effluent, the alumina removed 241 grains/cu.ft. At exhaustion, arsenic removal capacity for B4 was 536 grains/cu.ft. versus 655 grains/cu.ft. for Run A1 a 18% reduction.

Prior to regeneration, the adjusted raw water pH was lowered to 5.5 to determine if any additional arsenic could be removed by the alumina. The results showed an additional 26 grains of arsenic was removed from 2,580 BV (19,300 gallons) at the lower pH.

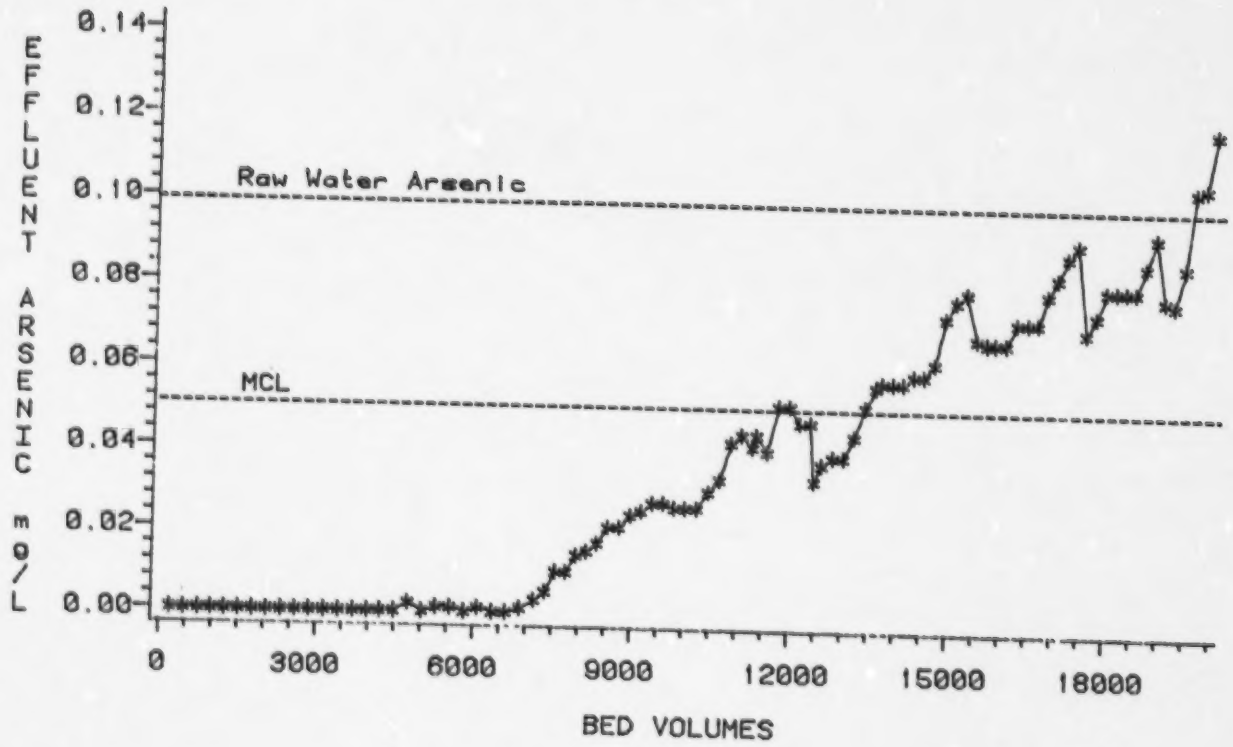


Figure 7. Column B Run 4 (pH 6.0)

This treatment run experienced the same problem with iron deposit buildup in the bed as did the treatment bed for Run A1. The column was backwashed once, and was also shut down for 13 days to observe a similar response in arsenic removal capability. Also, on April 15, 1982 a brief shutdown took place for relocating the laboratory trailer. The raw water arsenic level varied from 0.091 to 0.110 mg/L. The treated water arsenic level was at 0.108 mg/L at the termination of the run versus 0.083 mg/L for Run A1.

Acid consumption for the reduction of raw water pH to 6.0 was 0.107 gallons 66°B' sulfuric acid versus 0.129 gallons for the pH adjustment to 5.5 (17% reduction). Though this mode could reduce acid consumption slightly, and reduce the sulfate concentration in the treated water, these benefits are offset by more frequent treatment bed regenerations. The latter liability more than offsets the benefits by increasing operating labor costs, generating more wastewater, and producing higher chemical costs for regeneration. Therefore, although operating with treatment pH at 6.0 is technically feasible, it is offset by economic disadvantage and increased wastewater disposal volume.

Regeneration B4 took place on May 11, 1982. Wastewater volumes included 454 liters (120 gallons) of backwash water and 1249 liters (330 gallons) of regeneration wastewater and rinse. The regeneration procedure was modified to investigate a different regeneration/treatment concept for comparison to that employed in treatment method A. The same amount of 4% sodium hydroxide regeneration solution was used 181 liters (48 gallons). However, instead of using 91 liters (24 gallons) upflow and 91 liters (24 gallons) downflow followed by downflow neutralization, a total upflow procedure was used. The 181 liters (48 gallons) of 4% NaOH were pumped upflow followed

by upflow rinse, neutralization and treatment. An analysis of the regeneration wastewater indicated that 446 grains of arsenic were recovered from the treatment bed during regeneration. An apparent 114 grains of arsenic remain in the bed similar to the 137 grains that remained in the method A bed after regeneration A1.

Run B5 commenced on May 11, 1984. This treatment run was carried out upflow at 1.0 gpm with raw water pH adjusted to 5.5. This experimental treatment run provided a comparison of upflow treatment to downflow treatment of a regenerated treatment bed at the same pH (5.5) as that used in Runs A2 and A3. If successful, this could reduce the wastewater volume and eliminate requirement to backwash the bed. However, treatment capability compared unfavorably with the downflow mode. The treated water arsenic level did not reach the undetectable levels common to all downflow arsenic treatment runs; only a small amount of treated water 2,400 BV (18,000 gallons) had levels lower than 0.010 mg/L (Figure 8). The treated water arsenic levels also initially rose above the MCL on June 11 after treatment of 8,000 BV (59,200 gallons) compared to 13,000 BV (97,800 gallons) for run A2 and 14,800 BV (113,100 gallons) for run A3. The results suggest that the upflow operation is far more vulnerable to channeling.

Figure 8 shows that several points reflect some gain in capacity. As with other runs, this is a result of termination of flow for a short period of time. At 15,700 BV, the influent pH was lowered to 3.5. This condition caused a mild regeneration with an arsenic effluent increase during one day to 0.142 mg/L resulting in a slight gain in capacity.

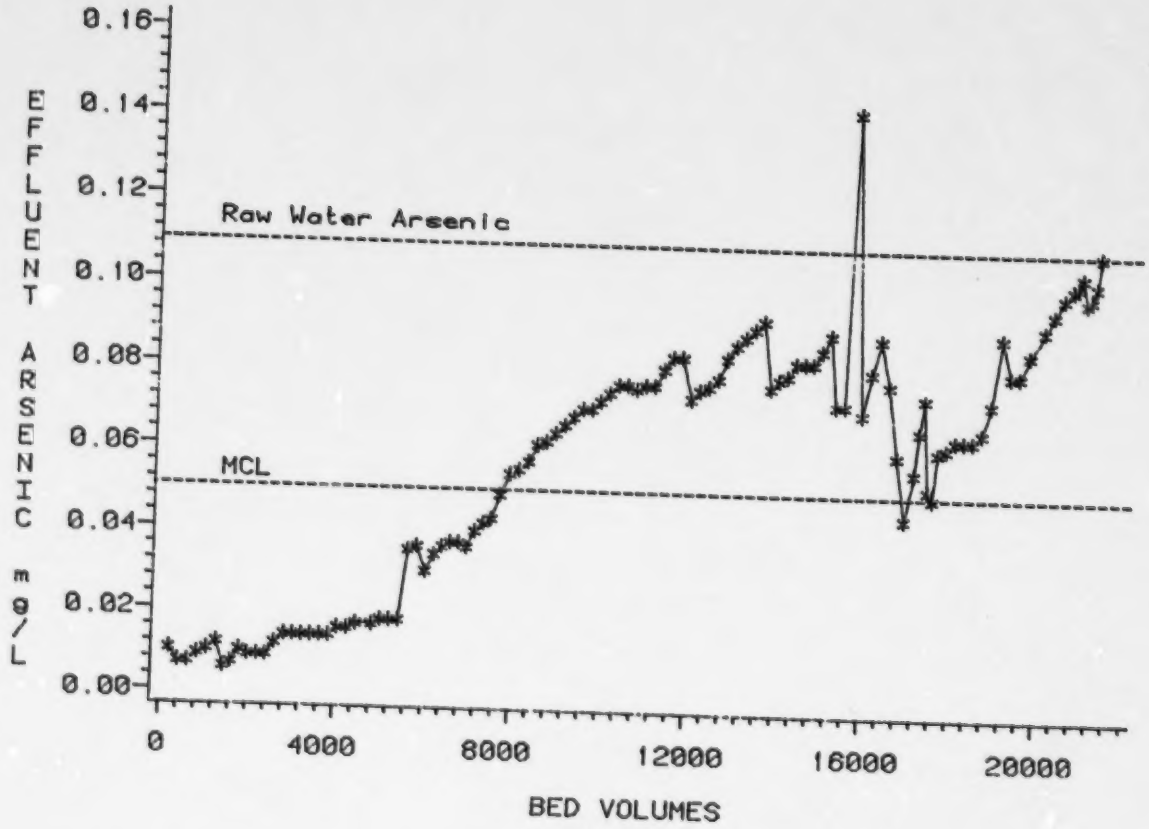


Figure 8. Column B Run 5 (Upflow)

Various methods for restoring arsenic removal capacity to a spent treatment bed were also attempted. On July 19 after treating 13,639 BV (102,000 gallons) and removing 389 grains of arsenic the treatment bed was virtually expended (arsenic level of the treated water was 0.091 mg/L). On that day, the bed was backwashed and treatment was stopped for two days; no significant improvement was obtained. On July 29 the treatment run was stopped again for two days (without backwashing); a small amount of treatment capacity was restored. On August 6, 1982 16,400 BV (122,800 gallons) the flow rate was reduced to 0.5 gpm which resulted in a gradual improvement in arsenic removal performance. The treated water arsenic level dropped as low as 0.044 mg/L and then gradually increased to 0.106 mg/L on September 23, 1982 when the run was terminated after treatment of 21,308 BV (159,320 gallons) and the removal of 488 grains of arsenic (compared to the treatment of 158,870 gallons and the removal of 730 grains of arsenic during Run A3). Table 3 shows capacity calculations at the MCL and media exhaustion.

Regeneration B5 did not take place until November 7, 1982. The regeneration method used two 90 liter (24 gallon) batches of 4 1/2% sodium hydroxide solution (one upflow and one downflow as used in Regeneration A2 and A3. Wastewater volumes included 454 liters (120 gallons) of backwash water and 1249 liters (330 gallons) of regeneration wastewater including rinse. Analysis of the regeneration wastewater indicated a removal of 463 grains of arsenic from the bed. This batch of regeneration wastewater was also retained for precipitation, sedimentation and sludge dewatering treatment.

Comparison of Treatment Methods

Although several different conditions for arsenic removal were examined in this study, it was obvious that the arsenic was best removed when the raw water was acid treated to pH 5.5 before treatment with activated alumina. Figure 9 shows the relative performance of treatment method A (activated alumina, pH 5.5) treatment method B (activated alumina, pH 9.0) and treatment method C (strong base anion resin, pH 9.0). Run 1 of each method were compared in Figure 9. Using the activated alumina with the raw water acidified to pH 5.5 (column A) arsenic concentration in the effluent exceeded the MCL only after 15,000 BV were treated. In the pilot test this volume corresponded to treating 112,000 gallons with one cu.ft. of alumina. In contrast, the treated water from B and C columns reached the arsenic MCL (0.05 mg/L) at about 500 BV or 3740 gallons.

In Figure 10 another comparison of test runs is made. This graph compares test run A3 with B4 and B5. Both B4 and B5 performances are not as good as A3, but B4 removes the arsenic nearly as well as A3 up to 6000 BV. Test run B4 reaches the arsenic MCL at 12,500 BV, B5 reaches it at 7500, and A3 reaches it at 15,000. The sharp decrease in effluent arsenic concentration of run B5 at 16,000 BV is the result of lowering the flow rate through the column from 1 gpm to 0.5 gpm as discussed in the previous section.

Figure 11 shows the effect of raw water pH (5.5, 6.0, and 9.0) on the capacity of the activated alumina to remove arsenic. At pH 9 (run B1) the arsenic MCL was reached at 800 BV. For run B4 at pH 6, the MCL was reached at 11,500 BV. At pH 5.5 (run A1) reached the MCL at 15,000 BV. For

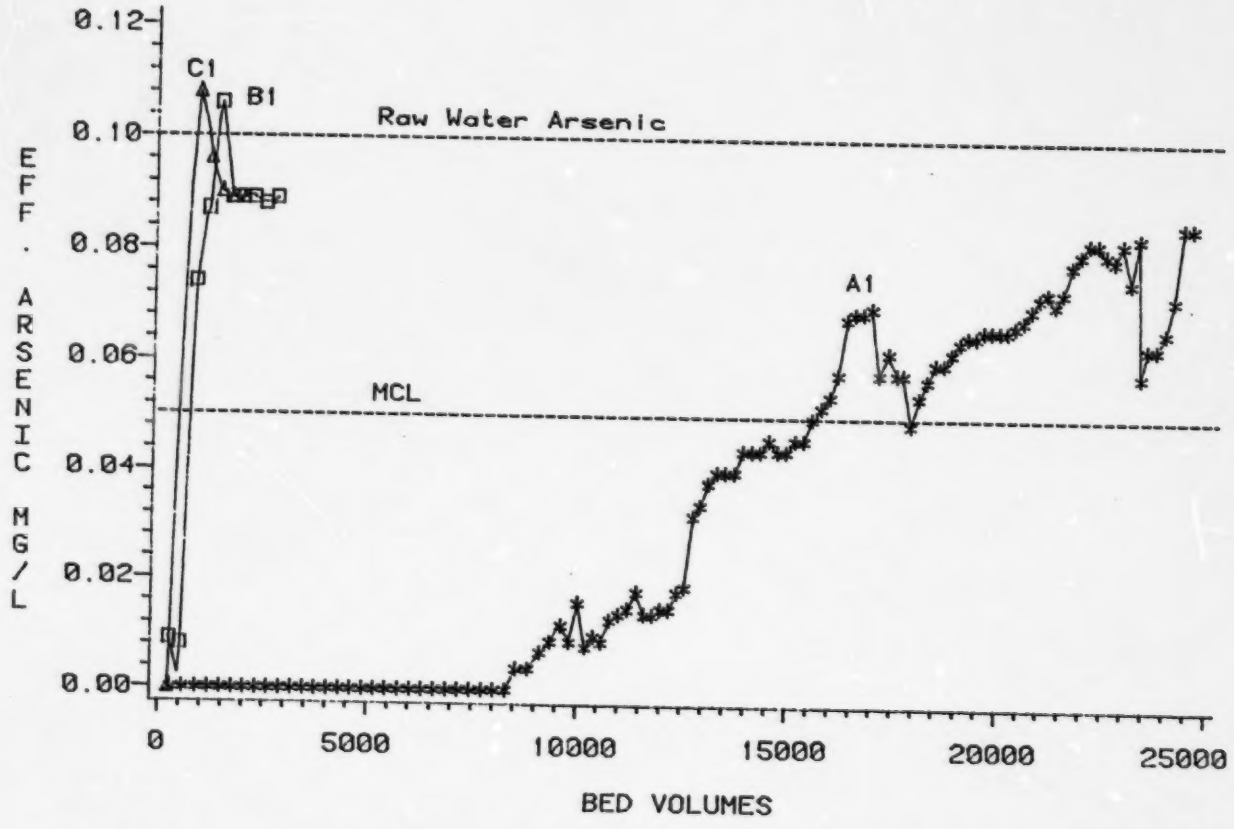


Figure 9. Run 1 Column Comparison (A,B,C)

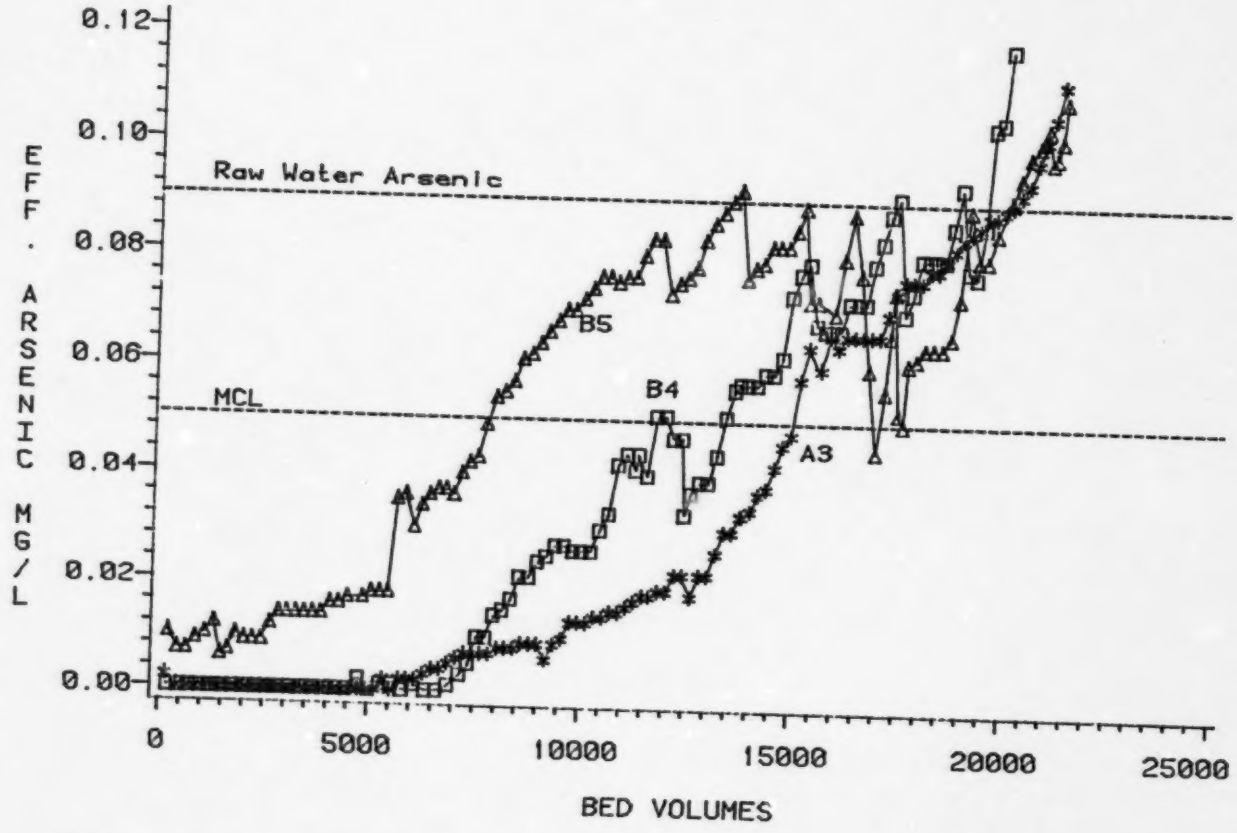


Figure 10. Comparison of Optimum VS Non–Optimum

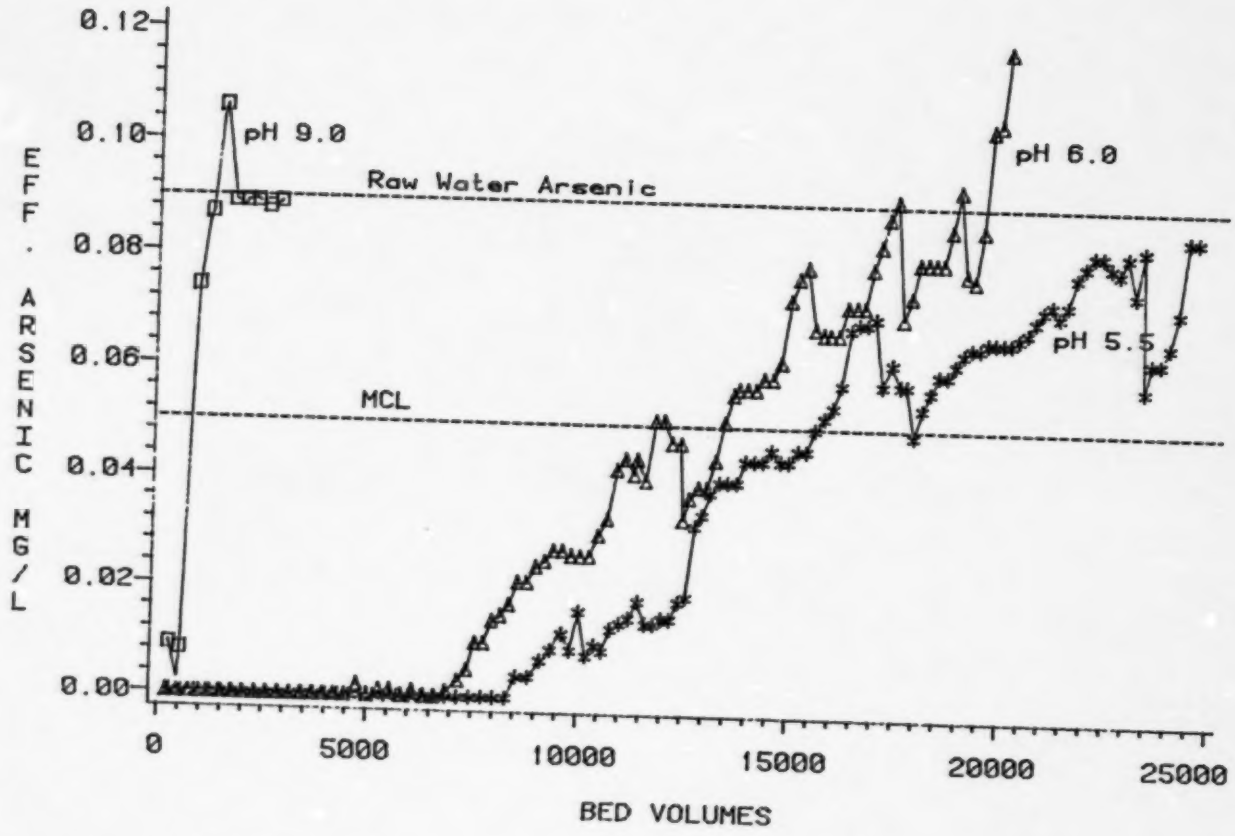


Figure 11. Effect of Raw Water pH on Arsenic Removal

the three pH's tested, the results clearly showed that pH 5.5 was the optimum for arsenic removal.

Other Ions Affected by Treatment

Each of the treatment methods studied in this project had a predicted effect on the treated water quality. Column A was run with the raw water pH controlled to 5.5. The acidification was accomplished using dilute sulfuric acid and therefore the treated water had a higher sulfate concentration than the raw water because sulfate is not removed by the alumina. Acid was not added to column B or column C. However, column B, operated at pH 9.0, removed silica from the raw water. The result was a short cycle since silica is removed preferentially to arsenic at pH 9.0. Influent silica was 28 mg/L. Figure 12 shows silica removal in run B1. Silica removal is 80 - 90% before 500 BV of water are treated. Figure 4 shows that arsenic breakthrough occurred before 500 BV.

Column C, containing the strong base anion resin, performed similar to column B for arsenic removal but, the resin perferentially removed sulfate instead of arsenic or silica. Figure 13 shows the result of sulfate removal in column C. Sulfate removal was 90 - 100% up to 500 BV. Referring to Figure 5 arsenic breakthrough is shown to occur before 500 BV were treated in cycles C2 and C3.

The fluoride concentration was also affected by treatment. Fluoride removal was most evident in treatment method A. Figure 14 shows fluoride removal for run A1 where the raw water fluoride concentration was 0.70 mg/L. About 90% was removed by the alumina at the very beginning of the cycle and the removal steadily decreased to 0% after 7000 BV of water were

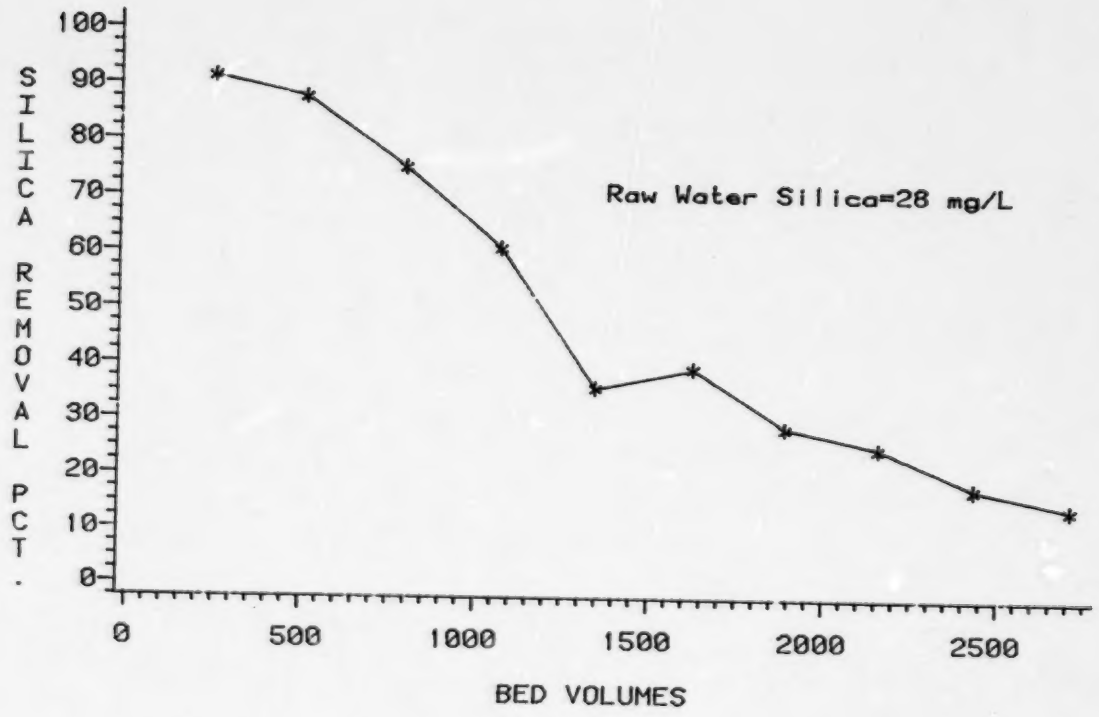


Figure 12. Silica Removal With Activated Alumina (pH 9.0)

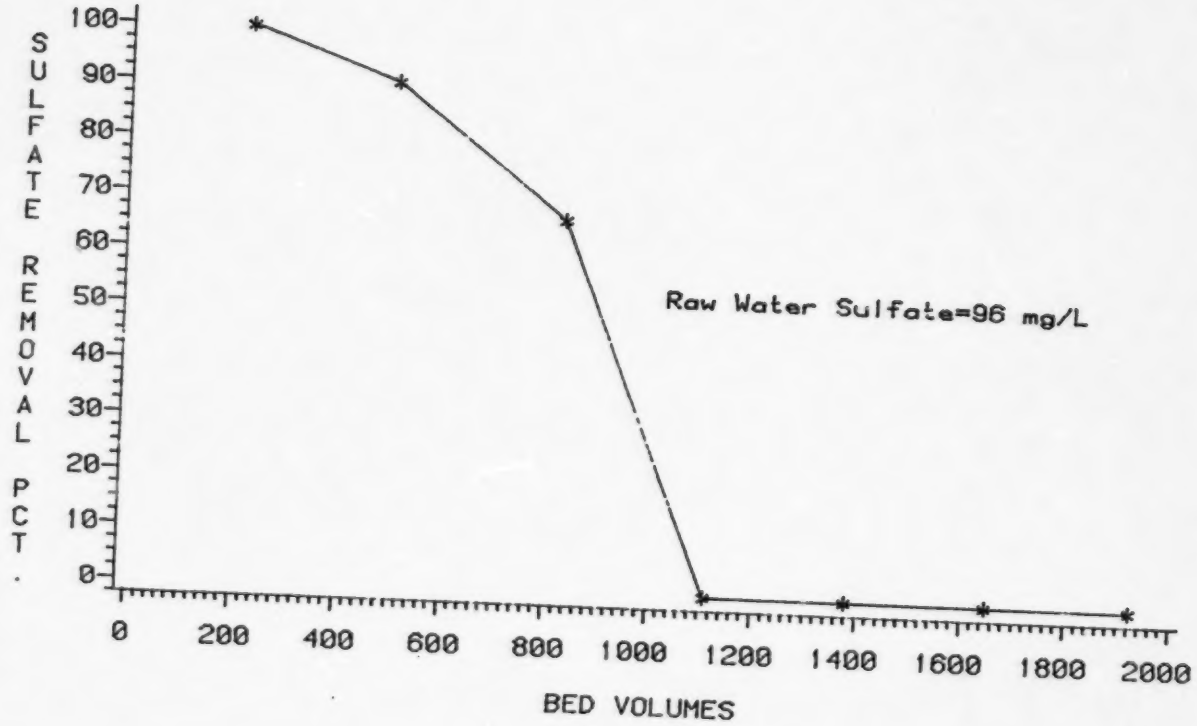


Figure 13. Sulfate Removal With Anion Resin (pH 9.0)

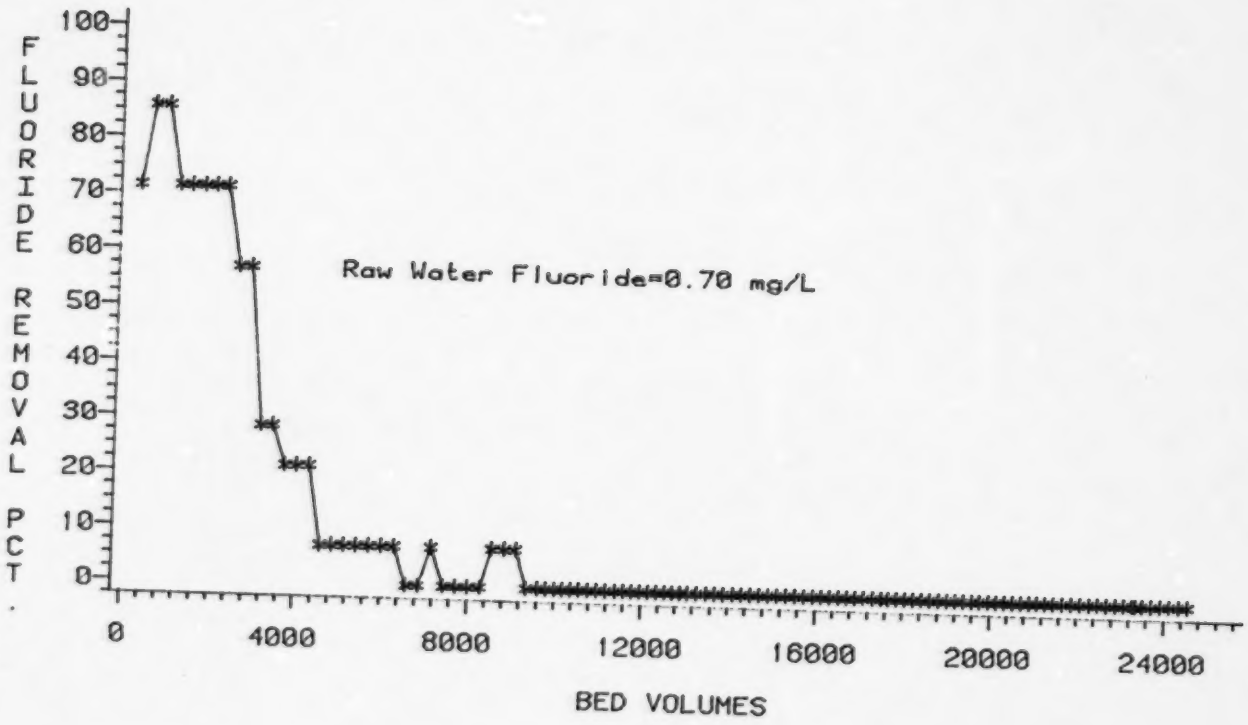


Figure 14. Fluoride Removal By Activated Alumina (pH 5.5)

treated. As shown in Figure 1, arsenic continued to be removed after the 7000 BV mark.

TDS was increased in column A treatment from 535 to 630 mg/L while alkalinity was decreased from 240 to 30 mg/L. Sulfate was also increased from 96 to 290 mg/L as was aluminum from not detected to 0.02 mg/L. Table 5 gives a full analysis of raw, treated, aerated, and blended water from column A, run A3.

Regeneration of Treatment Media

Each activated alumina column (A & B) was operated through three cycles, each consisting of: loading, backwashing; regenerating, and neutralizing. The specific processes for regeneration are described in discussion of each treatment method. A complete log of column A first regeneration (A1) is attached in Appendix A. Column B was regenerated in the same manner as column A except that the pH of the rinse was only reduced to 9.0.

Column C (strong base anion resin) was regenerated with 10% NaCl solution. The column was loaded, backwashed, regenerated, rinsed, and placed back on stream for production. The log of column C regeneration is also in Appendix A.

Based on the analyses of regeneration waste composite samples from run A1 it appears that the regeneration with 4-4.5% NaOH recovers about the same amount of arsenic average 35 grams (534 grains) from the activated alumina regardless of the quantity loaded on the alumina. Table 6 shows the quantity accumulaced on the column and the quantity recovered in regeneration for regeneration of method A only. Percent recovery varied from 79.1% to 58.6%. However, due to very high TDS in the regeneration

wastewater, it is difficult to accurately determine the relatively small percentage of arsenic. The arsenic analytical results for the wastewater composite samples were not verified by other laboratories. Therefore, the arsenic material balance reported in Table 6 may be in error.

Waste Handling of Activated Alumina Regenerant

Each time the activated alumina became saturated (exhausted) with arsenic, the media was regenerated. This process produced a waste stream high in arsenic and other inorganic compounds. Disposal of this waste must be handled in a safe manner. Table 7 lists the waste characteristics generated in several composite samples taken during the regeneration of column A run A1. Each composite sample was 208 liters (55 gallons) and the total, 1457 liters (385 gallons), represents all of the waste regeneration stream excluding the backwash. Analysis of the backwash water showed little difference from the raw water. Table 8 is a summary of each cycle from column A runs A1, A2, A3. Although the arsenic concentration is quite variable 23.1 mg/L, 41.2 mg/L, 29.0 mg/L for each regeneration stream, the quantity of arsenic removed by the activated alumina are quite similar: 518, 527, 557 grains/cu. ft. respectively as shown in Table 8.

Under present EPA regulations,(10) a waste stream with 5 mg/L of soluble arsenic is classified as a toxic waste and must be handled and disposed in an approved hazardous/toxic waste landfill. Because the disposal of these wastes can pose a problem to small treatment facilities, a limited investigation was conducted on scope of work for this project, was disposal procedures and methods for these high arsenic wastewaters. After each regeneration, the high pH regeneration wastewater was neutralized

Table 6. Regeneration Efficiency of Activated Alumina Test at pH 5.5

Column A Run No.	Arsenic accumulated on Column (grains)	Arsenic removed from Col. (grains)	% Recovery
1	655	518	79.1
2	(611+137)=748	527	70.5
3	(730+221)=951	557	58.6

Table 7. Regeneration Waste Characteristics (Run A1)

Sample ID	Waste Volume(gal)	-Concentration of Inorganics (mg/L)- Na	CL	AL	F	As	pH of Waste
1st Composite (NaOH)	55	33,380	425	1100	320	120	12.1
2nd Composite (rinse)	55	2,550	280	600	200	13.1	12.0
3rd Composite (rinse)	55	960	110	20	15	2.9	11.5
4th Composite (rinse)	55	598	120	14	9	1.2	11.0
5th Composite (rinse)	55	26,000	325	600	40	21	12.2
6th Composite (rinse)	55	2,000	125	60	10	2.4	12.0
7th Composite (rinse)	55	943	100	10	4	0.8	11.5

Table 8. Summary of Column A Waste Characteristics

Sample ID	Waste Volume(gal)	Concentration of Inorganics (mg/L) Na	CL	AL	F	As	pH of Waste
Total A1	485	> 9,550*	212	343	85*	23.1	11.7
Total A2	300	> 32,000*	688	702	—	41.2	12.0
Total A3	330	> 17,000*	610	510	82*	29.0	12.0

*Concentration too high - interferences in analysis - questionable results

for disposal. Initially the pH of the wastewater was adjusted from pH 12 to the 8.5-9.0 range by addition of 66°B' sulfuric acid. The results of this procedure showed that some of the aluminum in the wastewater precipitated out of solution pulling down a large amount of the arsenic with it. By lowering the pH further to the optimum range for aluminum precipitation, pH 5.0-6.5, the arsenic in the supernatant dropped to the level of the raw water, 0.1 mg/L. The volume of the supernatant, amounting to approximately 80 percent of the total wastewater, can then be decanted and discharged directly to the sewer (after mixing, the pH rises to 6.5, or above). The remaining 20 percent of the waste water was an alum type sludge of very low solids concentration. Bench scale, dewatering experiments were tried in the laboratory trailer employing various coagulant aids and filtration concepts. Eventually it was determined that by means of polymer addition and commercially available filtration devices the sludge could be reduced to a relatively "dry cake" form for disposal. Futhermore, the filtrate produced was almost identical in chemical quality to the supernatant described above; therefore, it could also be discharged to the sewer.

Finally, leachability of the dewatered solids (15-20% solids) was investigated by performing the EPA Toxicity Extraction Procedure (EP) to determine whether the filtered material was satisfactorily stable. To be classified as non-hazardous, the arsenic level must be lower than 5.0 mg/L in a pH solution of 5.0 at the completion of the extraction procedure. After completion of a series of extraction tests, arsenic levels in the extract ranged from 0.17 to 0.33 mg/L, all well under the 5.0 mg/L limit. The same procedure was run at a pH of 9.0 (in lieu of 5.0) with no increase of arsenic in the extract.

The results of these findings were brought to the attention of the NAS & EPA along with the recommendation that additional investigative work be accomplished on a larger scale with the two 1249 liter (330 gallon) batches of regeneration wastewater which would soon be available (Regeneration A3 and Regeneration B5). A contract extension was authorized to include an investigation of dewatering regeneration wastewater sludge with commercially available dewatering equipment. Screening of commercially available dewatering equipment quickly narrowed the selection to (1) Belt Filter Press and (2) Solid Bowl Centrifuge.

Contacts with equipment manufacturers resulted in the selection of one of each dewatering test device using the wastewater from the above mentioned regenerations. During the period December 14-16, 1982 the dewatering pilot plant equipment was delivered, set up, operated, and removed from the test site. The two batches of regeneration wastewater were pH adjusted to 5.5 and allowed to settle. The supernatant was decanted from the holding tanks to the sewer; the settled sludge was then

made available to two technicians who each independently performed screening of polymers, selection of polymer dosages, and finally dewatering of the sludge to produce an optimum "dry cake" for each system. Each dewatering system demonstrated the capability of producing "dry cake" which could be easily and safely handled in an operational treatment plant. For full scale treatment plant design purposes the belt filter press was selected due to its ability to produce "dry cake" with a higher solids content (15%+) and its lower capital cost.

Samples of "dry cake" were forwarded to the USEPA Environmental Monitoring Systems Laboratory - Las Vegas for EP testing. This testing was performed by the EPA testing contractor, Lockheed Engineering and Management Services Company, Inc. The results, which were reported on February 17, 1983[9], indicated that though the arsenic level in the dry cake was 1627 mg/kg, the arsenic level in the extract from the solid bowl centrifuge dry cake was 0.036 mg/L. The belt filter press dry cake was 3,325 mg arsenic/kg solids and the extract from the dry cake was only 0.046 mg/L. Both extracts were well within the maximum allowable arsenic limit of 5.0 mg/L. The Nevada state regulatory agency[11] allows this waste material to be placed in suitable sanitary landfills. For a small water treatment plant mechanical dewatering may be too expensive but if sand drying bed space is available that may be more economical.

Cost Estimates

Although the pilot study was performed at the NAS in Fallon, NV, the results apply to two other water supplies, the City of Fallon and The Fallon Indian Reservation, using ground water from the same aquifer. Based

upon the results of these studies, preliminary designs with cost estimates were developed for all three water supplies (see appendix B). The design flows for the three systems are 700 gpm for the NAS, 2400 gpm for the City of Fallon and 100 gpm for the Fallon Indian Reservation. The basic designs varied with community size and distribution system. Capital costs for each system was estimated at $558,000, $1,343,000, and $179,000 respectively. Operation and maintenance costs in ¢/1000 gallons treated are: 22.1, 31.8, and 29.8 respectively. A complete discussion of preliminary design and estimated costs is contained in a separate report.[7]

Conclusions

The pilot plant project at the Fallon, NAS resulted in the following conclusions about the treatment methods studied for removing arsenic from drinking water.

(1) Activated alumina is very efficient for removing arsenic (arsenic V) at or near the optimum pH of 5.5.

(2) As the pH is increased above 5.5, the capacity for arsenic removal by activated alumina treatment decreases.

(3) The efficiency of treatment using a strong base anion exchange resin is dependent on the quantity of other anions in the water, especially sulfate which is preferentially removed before arsenic. The sulfate concentration (96 ug/L) of Fallon raw water was too high to allow efficient removal of arsenic by anion exchange.

(4) Activated alumina treatment increases the TDS (primarily sulfate) of the final product depending on the extent of pH adjustment before and after treatment. The final quality also depends on the ratio of blending

treated and raw water.

(5) The operation of an activated alumina process at pH 5.5 lowers the alkalinity of the treated water. The product water alkalinity must be adjusted by blending or chemical addition for stabilization before distributions.

(6) Fluoride is removed along with arsenic when activated alumina is used at pH 5.5. However, fluoride breakthrough occurs long before arsenic breakthrough. Blending raw and treated water will allow some fluoride to be present in the product water if the amount of fluoride for dental benefits is required.

(7) Within an arsenic concentration near 0.1 mg/L, activated alumina treatment system of pH 5.5 and a flow rate of 1.0 gpm will operate for approximately 3 months before regeneration is necessary.

(8) The waste stream, from regeneration of column A, contained soluble arsenic at levels classified as hazardous wastes by U.S. EPA regulations. However, the waste can be neutralized with acid resulting in the arsenic precipitating from solution. The solids containing arsenic are non-leachable according to the U.S. EPA EP Toxicity Test.

(9) Based upon preliminary system design for the Fallon Naval Air Station, City of Fallon, and the Fallon Indian reservation, operation and maintenance costs for activated alumina treatment at pH 5.5 will range from 22-30 ¢ per 1,000 gallons of treated water.

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8. APHA-AWWA-WPCF, "Standard Methods for the Examination of Water and Wastewater - 15th Edition", 1980.

9. Letter: Lockheed Engineering and Management Services Company, Inc. to EPA, "Arsenic Analyses - Arsenic Removal Pilot Plant, Fallon, Nevada", dated February 17, 1983.

10. Federal Register/Vol. 45, No. 98/Monday May 19, 1980, Table 1.

11. Letter: State of Nevada Department of Conservation and Natural Resources Division of Environmental Protection to Rubel and Hager, Inc., "Arsenic Waste Disposal, Fallon, Nevada", dated February 2, 1983.

APPENDIX A

April 4, 1982

A Column Regeneration 1st. Regen.

Procedure:

1. Backwash Media ten minutes 4-6 gpm
2. Drain Column
3. 24 gal. 4% NaOH Solution upflow thru bed (35 min.)
4. Follow Regen. Solution iwth upflow rinse 1.5 gpm - 60 min.
5. Drain Column
6. 24 gal. 4% NaOH Regen. Solution downflow (35 min.)
7. Follow Regen. Solution with Raw Water (1.5 gpm - 15 min.)
8. Continue Downflow Rinse - infl. pH adjust 2.5
9. When eff. pH = 90 adjust infl. pH to 4.0 - (start Production)?
10. When eff. pH = 6.5 adjust infl. pH to 5.5 for remainder of run.

Regen. Solution = 24 gal. H^2O/1.26 gals. 50% NaOH

Time			
	Drain Column		
8:40	Start Backwash upflow		
8:45		Sample	A-1-1-0 Time
8:50			A-1-2-5 EPA
8:55			A-1-3-10
9:00	End Backwash		A-1-4-15 EPA
	Drain Column.	85 gal.	A-1-5-Comp. EPA
9:20	Start upflow Regen. Solution	0.7 gpm	
9:42		Sample	A-1-6-0 Time
9:47	End Regen. Solution (let set	21 min.)	A-1-7-5 EPA
10.08	Start Rinse 1.5 gpm		
10:13			A-1-8-10
10:18			A-1-9-15 EPA
10:28		55 gal.	A-1-10-Comp. EPA

Continued

April 4, 1982

A Column 1st. Regeneration Continued

Upflow Rinse Cont'd

Time		sample#	
10:48			
10:58			A-1-13-45 EPA
11:08			A-1-14-55
			A-1-15-65 EPA
11:18		55 gal.	A-1-16-Comp.
11:28			A-1-17-75
11:38	pH = 11.25		A-1-18-85
			A-1-19-95
11:48		55 gal.	A-1-20-Comp.
11:58			A-1-21-105
12:08			A-1-22-115
12:18	pH = 10.8 End upflow Rinse		A-1-23-125
	55 gal. H^2O/32 ML H^2SO^4 = 9.5		A-1-24-135
	Drain to Media		A-1-25-Comp.
12:30	Start Regeneration Downflow		
	Fill Column		
12:50			
2:55		Sample#	A-1-26-0
1:00	Regen. Solution off (let set 25 min.)		A-1-27-5 EPA
1:30			A-1-28-10
1:40			A-1-29-15 EPA
	11.7 pH M-184880		A-1-30-25
1:50	Start Low pH Rinse - 2.5 pH infl.		
2:00	11.7 pH		A-1-31-35
2:10			A-1-32-45
	55 gal. H^2O/32 ML H^2SO^4 = pH 9.4		A-1-33-55
2:20			A-1-34-Comp.
2:30	11.5 pH		A-1-35-65
2:40	P.M.		A-1-36-75
2:50			A-1-37-85
			A-1-38-95 EPA

Continued

April 4, 1982

A Column 1st. Regeneration Continued

Time			
		55 gal.	A-1-39-Comp.
3:00			A-1-40-105
3:10			A-1-41-115
3:20			A-1-42-125
3:30			A-1-43-135
3:40			A-1-44-145
		55 gal.	A-1-45-Comp.
3:50	AS = .30		A-1-46-155
4:00	30 gals./15 ML H^2SO^4	pH 9.4	A-1-47-165
4:10 pH 11.0	AS = 0.20		A-1-48-175
4:25	30 gals. H^2O/10 ML H^2SO^4		
5:00 P.M.	M-185090 (210 gals.) (3 gals. H^2SO^4 solution)		A-1-49-10 pH
5:30	Adjust infl. pH to 4.0 M-185140		A-1-50- 9 pH
6:00	Eff. pH = 7.3		
6:30	Eff. pH = 6.5 - Adjust infl. pH to 5.5 M-185200		
	AS = .130		
	Neutralization Rinse to 6.5 pH = 320 gals.		

April 5, 1982 - 247 ML H^2SO^4 used -

Required 3.3 gals. H^2SO^4 Solution -

Solution = 75 ML H^2SO^4/gal. H^2O

7:00 A.M. Infl. pH = 5.55 Eff. pH = 4.3 AS = .033 F = .55

3:00 P.M. Infl. pH = 5.6 Eff. pH = 4.6 AS = .002

C COLUMN REGEN #1
DECEMBER 29, 1981

1. Catch spent media sample
2. Backwash media 15 minutes
3. Drain to media
4. Pass 125 gallons 10% NaCl solution downflow 1 gpm
5. Continue downflow 1.5 gpm with raw water for 25 minutes
6. Start process run

12-29-81

7:45 A.M.	Start backwash (2 gpm)			
	0 sample	#C1-0-0		
7:50	sample	C1-1-5	g	
8:00	sample	2-15	g	
	End backwash - Composite -30 gal.	3		
	Drain to media			
8:17	Start regen. solution (10% NaCl) (125 gals.) Down Slow 1 gpm			
8:41	0 sample	4-0		
8:46	sample	5-5		
8:51	sample	6-10		
8:56	sample	7-15		
9:06	sample	8-25		
9:16	sample	9-35		
9:26	sample	10-45		
9:36	sample	11-55		
9:46	sample	12-65		
9:56	sample	13-75		
10:00	Composite sample (55 gal.)	14-		
10:10	sample	15-85		
10:20	End Regen.	16-95		
	Drain column - Composite (55 gal.)	17		
	Start regen. downflow rinse			
10:35	0 sample	18-0		
10:45	sample	19-10		
10:55	sample	20-20		
11:05	sample	21-30		
	End Regen rinse	22-40		
11:10	Start process run - M-15145			
3:30 P.M.	eff. pH - 7.45 sample	23	M-15560	
6:30	sample	24	M-15820	
9:30	sample	25	M-16160	
12:30 A.M.		26		
3:30		27		
6:30 A.M.	sample	28	M-17050	
9:30	sample	29	M-17315	
12:30	sample	30	M-17573	
3:30 P.M.	sample	31	M-17880	

APPENDIX B

Cost Estimates

CAPITAL COST ESTIMATE

Costs presented in this section are based upon quotes obtained during January 1983 and revised during May 1984. These costs are subject to change on short notice. The estimate does not include costs for land, financing, or taxes. In all cases, the concept design is based upon implementing treatment sites presently in the possession of the individual utility or its owner. Investigation of funding methods for capital expenditures is not included in the scope of this project.

The implementation of the arsenic removal treatment facility criteria for the three separate water utilities at Fallon entails custom features for each system. Even though each utility employs its own wells, it is assumed that the raw water quality is identical for each utility. Physical differences exist between the configuration of the existing distribution and storage systems of the three utilities. Because of these differences, modifications required to integrate the treatment function into the existing systems vary between utilities. The basic major equipment item sizes, and the modifications required for each utility that are incorporated in each system are described below.

A. NAS Fallon

There are three (3) wells located at a site off the base that are manifolded together into a 14"ø water main. The water main flows into two (2) 500,000 gallon storage tanks centrally located on the base. Water in storage is presently repressurized into a distribution system. Well pumps are controlled by the water level in the storage tanks.

The treatment system will be located adjacent to one of the existing water tanks. The treatment plant influent pipe will be tapped into the 14"ø main. The water will flow into the plant where part of the water will be treated and part will bypass treatment.. Both will flow from the treatment building into the adjacent storage tank where the blending will take place.

The treatment system includes (1) two vessel train. Each vessel is ten foot diameter with a five foot deep bed of treatment media (volume 380 ft^3). The regeneration wastewater surge tank is 40 foot diameter by 20 foot high to contain 125,000 gallons of regeneration wastewater. The anticipated annual volume of wastewater is 375,000 gallons based upon three regenerations per year. The projected weight of solids is 3,200 lbs/year; dewatered cake weight is projected at 21,400 lbs/year.

An automatic shutoff valve will be installed in the 14"ø main downstream of the treatment plant tie in. This valve will be normally closed. However, in emergency situations, the valve will automatically open

permitting large volumes of water to bypass treatment and flow directly to the storage tanks.

B. City of Fallon

There are three (3) wells located at separate sites in the north central sector of the City. The three wells pump directly into the distribution system at different locations. The mains connect to conduits directed to two elevated storage reservoirs (one-1,000,000 gallon and one-2,000,000 gallon) which maintain system pressure. The well pumps are presently controlled automatically by the liquid level in the reservoirs.

A treatment plant site recommended by the City adjacent to one of the wells, (No. 3) in a park owned by the City has been selected as the preferred location. A new 14" ϕ pipe is required to manifold the three (3) wells for delivery of the raw water to the treatment plant. This manifold can take various routes. The cost included in the estimate for this item is based upon the shortest routing. Optional routings are available at approximately the same cost. In order that emergency high pressure high water flow capability be available, the City has requested bypassing the treatment system. This option would be operated manually. This redundancy in pump capability results in increased pumping costs.

The raw water entering the treatment building can be treated in one or two treatment trains. This will be an operator selected option which will normally be a function of seasonal consumption. During periods of light to moderate consumption, one well's production will suffice. This production will be treated in one treatment train. During periods of heavy consumption, production of two wells will be required necessitating the employment of two treatment trains. In the future, consumption may grow to the level where the production of three wells will be needed. At that time, a third treatment train will be required. Present capital cost planning includes the space, pipe connections, electrical service and other miscellaneous provisions required for installation, operation and maintenance of the future third treatment train.

The treatment system includes (2) two-vessel treatment trains (with provision for a future third train). Each vessel is twelve foot diameter with a six foot deep bed of treatment media (volume 678 ft^3). The regeneration wastewater surge tank is 54 foot diameter by 20 foot high to contain 225,000 gallons of regeneration wastewater. The anticipated annual volume of wastewater is 1,350,000 gallons based upon six regenerations per year. The projected weight of dry solids is 11,500 lbs/year; dewatered cake weight is projected at 76,500 lbs/year.

The raw water flows to the designated treatment train where it proportionately split into treatment and bypass raw water flows. The flows rejoin in the clearwell where blending takes place. Water is then

pumped from the clearwell into the distribution system through a new treated effluent main.

C. Fallon Indian Reservation

There is one (1) well located at a site owned by the tribe at the Indian Colony. Adequate space is available at that site for installation of the arsenic removal water treatment plant. The existing pump discharge pipe is to be tapped for a supply and return line to and from the treatment plant with a bypass shutoff valve installed between. The raw water supply splits into treatment and bypass branches. Both branches feed into a clearwell where blending takes place. The blended treated water is then repressurized into the distribution and storage system.

The treatment systems includes (1) two vessel treatment train. Each vessel is five foot diameter with a three foot deep bed of treatment media (volume 60 ft^3). The regeneration wastewater surge tank is 18 foot diameter by 12 foot high to contain 20,000 gallons of regeneration wastewater. The anticipated annual volume of wastewater is 80,000 gallons based upon four regenerations per year. The projected weight of dry solids is 680 lbs/year; dewatered cake weight is projected at 4,500 lbs/year.

This system does not include a caustic storage tank or regeneration wastewater sludge dewatering equipment. It does include a plastic tank for holding 50 percent sodium hydroxide which is to be procured in carboy or 55 gallon drum quantities. It also includes a trailer mounted tank for transporting the regeneration wastewater sludge to either the NAS or City treatment systems which have included provisions for dewatering the sludge. Since the volumes of the above mentioned liquids are small, the equipment cost savings can be incorporated.

At present there is no sewer available for wastewater discharge at the proposed treatment plant site. The City does plan to run a sewer line to the site in the near future.

The estimated capital cost summary foe each of the above arsenic removal water treatment plants is exhibited in Figure 2.

ESTIMATED CAPITAL COST SUMMARY
ARSENIC REMOVAL WATER TREATMENT PLANTS.
(May 1984 Costs)

PROCESS EQUIPMENT	700 gpm NAS	2400 gpm CITY	100 gpm RESERVATION
Treatment Vessels w/platform & Chemical Storage Vessels	75,000	146,000	29,000
Treatment Media	28,000	88,000	5,600***
Process Piping, Valves & Fittings	20,000	75,000	6,000
Instrumentation and Controls	16,000	33,000	4,200
Chemical Feed Systems	9,000	16,000	4,200*
Forced Draft Aerators	17,000	40,000	11,000
Wastewater Surge Tank(w/mixer)	85,000	110,000	25,000
Wastewater Sludge Dewatering Equipment	42,000	42,000	4,000**
Subtotal	292,000	530,000	89,000
INSTALLATION & CIVIL			
Process Installation (Mechanical, Electrical & Paint)	74,000	137,000	21,000
Building & Concrete	66,000	165,000	18,000
New Water Main to Manifold Wells	-	176,000	-
Modification to existing well pump, control & pipe	11,000	22,000	3,000
Prepressurization Pumps & Tie-in to existing mains	-	44,000	6,000
Site Work (Treatment Plant Site)	6,000	24,000	3,000
Subtotal	157,000	568,000	51,000
MISCELLANEOUS			
Contingencies (10%)	45,000	112,000	14,000
Engineering (Design & Procurement)	40,000	80,000	15,000
Construction Supervision	18,000	25,000	5,000
Start-up, Operator Training & O&M Manual	6,000	8,000	5,000
Subtotal	109,000	225,000	39,000
TOTAL	$558,000	$1,343,000	$179,000

* Includes Caustic Day Tank & Pump. Caustic Storage Tank not required.

** Equipment to Transfer Sludge to NAS or City for dewatering.

*** If media is purchased jointly with NAS or City, $1,200 savings will result.

V. OPERATION AND MAINTENANCE COST ESTIMATE

Estimated operating and maintenance costs are summarized for each treatment system in Figure 3. Costs are indicated in cents per thousand gallons of treated water. Costs are based on current chemical, treatment media, labor and electric utility prices. For some items (e.g. replacement parts), values must be assumed. The average daily potable water consumption for each utility is assumed to be as follows"

NAS	-	0.5 MGD
City	-	2.0 MGD
Indian Reservation	-	0.1 MGD

The factors used to develop the cost estimates are presented below.

A. Chemicals

Chemical consumption was closely monitored during the pilot plant program. Chemical costs have fluctuated during the past year. However, current costs for chemicals delivered to Fallon in tank truck quantities are as follows:

66°B' H_2SO_4	-	$91.50/ton (7¢/gallon)
50% NaOH	-	$334.40/ton ($2.09/gallon) - Premium for drum or carboy quantities
Anionic Polymer	-	$2.40/lb. - 50# Bags-No tank truck delivery

B. Treatment Media

Material currently sells for $0.516/lb. in truckload (40,000 lb.) quantities of 100 pound bags. Treatment media density varies with the degree of packing of the bed; 50 lb/ft^3 is appropriate value. Freight to Fallon is approximately $0.15/pound. Cost is graduated upward for smaller quantities.

C. Operating Labor

Personnel used to operate treatment plants are required for part-time service. Their services are to be shared with other utility functions except for the City where a full time operator will be assigned exclusively to the treatment plant. Except for treatment bed regeneration which requires a full day, an average of two manhours per day is required at NAS, and one manhour per day at the Indian Reservation. Current hourly rates are as follows:

NAS	-	$13.50/hour
City	-	$13.65/hour
Indian Reservation	-	$ 7.50/hour

D. Electric Energy

The present Fallon electrical utility costs are 9.4732¢/KWH. 10¢/KWH was used to estimate these costs. NAS will not be faced with high energy cost because there is no requirement for repumping the treated water. Therefore, the electrical energy consumption is limited to fractional horsepower motors for chemical pumps and the forced draft aerator, lighting and other small loads. The City and the Indian Reservation are faced with repumping the treated water into distribution and elevated storage. since raw water is only pumped through treatment into the clearwell, the existing well pump operating pressure can be reduced. This will happen at the Indian Reservation; the result being a minimum net increase in electrical cost. However, the City desires to retain an optional capability to deliver maximum pressure from the existing well pumps throughout the distribution system for emergencies. With this concept, the electrical energy cost is exceptionally high.

E. Replacement Parts

An assumed figure based upon experience with comparable plants is used. The figure includes spare parts for equipment, expendable items (e.g. lubricants, containers for disposal of dewatered regeneration wastewater solids, etc.) and miscellaneous outside service (i.e. pump service).

NAS	-	$ 4,000/year
City	-	$12,000/year
Indian Reservation	-	$ 800/year

ESTIMATED OPERATION AND MAINTENANCE COST
ARSENIC REMOVAL WATER TREATMENT PLANTS
(May 1984 Costs)

Costs in ¢/1000 gallons per treated water

	NAS	City	Indian Reservation
A. Chemicals*			
1. Acid for Raw Water pH adjustment.	7.0	7.0	7.0
2. Caustic for regeneration	4.3	8.3	6.6
3. Acid for Treatment Bed Neutralization			
Acid for Wastewater Neutralization			
Polymer for Conditioning of Wastewater Sludge	1.0	1.0	1.0
B. Treatment Media Replacement*	1.0	1.0	1.6
C. Operating Labor	5.6	5.5	7.9
D. ELectrical Energy	1.0	11.4	3.5
E. Replacement Parts, etc.	2.2	1.6	2.2
TOTAL	22.1	31.8	29.8

* Costs based upon blend ratio of 75% treated water and 25% raw. (If the ratio of treated raw water were reduced, chemical consumption media replacement would be reduced.)

VI. SUMMARY

The capital costs for complete installed arsenic removal water treatment plants, excluding land, financing costs, and taxes are estimated to be:

NAS	-	$ 558,000
City	-	$1,343,000
Indian Reservation	-	$ 179,000

The operating and maintenance costs for each facility is estimated to be:

NAS	-	22.1¢/1000 gallons treated water
City	-	31.8¢/1000 gallons treated water
Indian Reservation	-	29.8¢/1000 gallons treated water

APPENDIX C

Analytical Test Methods for Analytes

Analyte	Test Method
arsenic	- Silver Diethyldithiocarbamate (Silver DDC)
fluoride	- SPADNS (Hach)
aluminum	- Aluminom Method using AluVer(R) Aluminum Reagent (Hach)
silica	- Silicomolybdate Method (Hach)
sodium	- Calculated (using balance of anions and cations)
carbonate	- Calculated (using total alkalinity and phenolphthalein alkalinity)
bicarbonate	- Calculated (using total alkalinity and phenolphthalein alkalinity)
sulfate	- Turbidimetric Method using SulfaVer (R)IV Sulfate Reagent (Hach)
pH	- Great Lakes Instruments, Inc. Standard Electrode
chloride	- Mercuric Nitrate Method (Hach)
magnesium	- Calculated (using total hardness and calcium)
calcium	- Titration Method using CalVer (R)II Calcium Reagent (Hach)
alkalinity	- Titration Method
total hardness	- Titration Method using UniVer(R)I Hardness Reagent (Hach)
TDS	- Calculated